Author Profile :- Dr. Gatete Marcel

Dr. GATETE Marcel holds a Doctor of Philosophy degree from Periyar Maniammai University, India 2012-2018, a Master of Philosophy from PRIST University, India 2010-2011, M.SC. In Information Technology from Bharathidasan University, India 2008-2010, B.SC in Computer Science Engineering From Institut Superieur Pedagogique de Gitwe, Rwanda 2002-2006. He is currently a Senior Lecturer in the Department of Business and Information Technology at UTB (University of Tourism, Technology, and Business Studies), Kigali, Rwanda, since 2021. His research interests span both computer programming and networking. Much of his work has been on improving the understanding, design, and performance of Mobile ad-hoc networks, mainly through the application of network programming, statistics, and performance evaluation. In the networking arena, he has worked on characterizing the Quality of Service of this type of Wireless network. He has explored the presence and implications of Quality of Service and heavy-tailed distributions in network traffic workloads. He has also investigated the implications of clustering for the design of scalable and cost-effective Mobile Ad hoc networks. In the Educational science arena, he has made numerous contributions to educational technology in practice research, mentorship, consultancy, and practical case studies. He is an active researcher and has published numerous paper various international Scopus peer-review papers, he has recently appeared among the Top 200 Scientists I AD Scientific Index 2022 Version. Email: gtmrcua@gmail.com

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Author's Bio

1. Name: Dr. GATETE Marcel

2. Profile Bio:

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ABSTRACT

Due to the complexity of real-time multimedia applications in MANET, various problems inherent to QoS provision inhibit the successful transmission of multimedia data. A major problem is related to the unpartitioned network which makes the network hard-manageable. The energy constraints are challenges facedas some nodes are dead due to their low battery power. Storm problems are related to the broadcasting nature of some routing protocols. Other major problems relate to the fairness and securityissues often neglected during data transmission.To address those problems, various robust QoS routing, multi-algorithm mechanisms have been proposed in this study, each one being a mixture of important QoS provision techniques namelyAnt Colony with Fuzzy Optimization techniques, Genetic Algorithms, Multicast Techniques, Power-Aware Routing Schemes, Clustering Mechanisms, Intrusion Detection Techniques, and Packet Scheduling schemes.

QAMACF (QoS-Aware transmission for Multimedia applications using Ant Colony with Fuzzy optimization), a prominent QoS protocol which is a combination of multicast techniques and ant colony with fuzzy optimization mechanisms was first proposed. GDAQM (Genetic with DPD for Attaining high QoS in MANETs) which is a combination of both Genetic and MDPD-k scheduling algorithms was implemented next. The third proposed scheme is MARMAQS (Multi-Algorithm Routing Mechanism for Acquiring high Quality of Service in MANET) consisting of QoS techniques namely lifetime prediction routing, packet scheduling, and the intrusion detection techniques. FSR-CAES (Full-Featured Secure Routing Clustering Algorithm with Energy-Aware and Scheduling capabilities for increasing QoS in MANET), a combination of numerous algorithms, each one containing one of the previously mentioned problems was fourthly proposed. Using the NS-2 simulator, the proposed schemes performed well by highly increasing the QoS during multimedia data transmission and finally, a comparative evaluation of the proposed protocols was then conducted, each scheme performed well for some experimentations and outperformed during others, hence, it was proved that our proposed protocols are well suited for real-time multimedia applications.

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LIST OF ABBREVIATIONS

ABR	Associativity-Based Routing
ABRP	Associativity Based Routing Protocol
AMRIS	Ad hoc Multicast Routing Protocol Utilizing Increasing ID numbers
AMRoute	Ad hoc Multicast Routing
AODV	Ad hoc On-demand Distance Vector
AWK	Aho, Weinberger, and Kernighan
CBR	Cluster-based Routing
CBRP	Cluster-based Routing Protocols
CEC	Cluster-based Energy Conservation
CGSR	Cluster Gateway Switch Routing Protocol
CPU	Central Processing Unit
CSMA/CA	*Carrier Sense Multiple Access with Collision Avoidance*
DAG	Directed Acyclic Graph
DBPSK	*Differential Binary Phase Shift Keying*
DCF	*Distributed Coordination Function*
DDoS	Distributed Denial of Service
DFIR	*Diffused Infrared*
DIFFSERV	*Differentiated Services*
DoS	Denial of Service
DQPSK	*Differential Quadruple Phase Shift Keying*
DREAM	Distance Routing Effect Algorithm for Mobility
DSCP	Differentiated Service Code Point
DSDV	Destination-Sequenced Distance-Vector
DSR	Dynamic Source Routing
DSSS	Direct Sequence Spread Spectrum
DT	Distance Table
DV	Distance Vector Protocol
FHSS	*Frequency Hopping Spread Spectrum*

FQMM	Flexible Quality of Service Model for MANETs
FSR	Fisheye State Routing Protocol
FSR-CAES	Full-Featured Secure Routing Clustering Algorithm with Energy-Aware and Scheduling capabilities for highly increasing QoS in MANET
GA	Genetic Algorithm
GAF	Geographic Adaptive Fidelity
GDAQM	Genetic with DPD for Attaining high QoS in MANET
GSM	Global System for Mobile communication
GSR	Global State Routing Protocol
HSR	Hierarchical State Routing Protocol
HSRP	Hot Standby Router Protocol
IDT	Intrusion Detection Techniques
IEEE	*Institute of Electrical and Electronics Engineers*
INTSERV	*Integrated Services*
IrDA	Infrared Data Association standard protocol
LAR	Local Aided-Routing
LCT	Link Cost Table
LET	Link Expiration Time
LLC	*Logical Link Control*
LORA	Least Overhead Routing Approach
LPER	Link Packet Error Rate
LRSS	Link Received Signal Strength
MAC	*Medium Access Control*
MANET	Mobile Ad hoc Network
MARMAQS	Multi-Algorithm Routing Mechanism for Acquiring high Quality of Service in MANET
MDPD-k	Modified Dynamic Priority with Deadline Consideration scheduling
MDR	Minimum Drain Rate
MRL	Message Retransmission List
OLSR	Optimized Link State Routing
ORA	Optimum Routing Approaches

PAN	Personal Area Networks
PAR	Positive Acknowledgment Retransmission protocol
PCF	*Point Coordination Function*
PDA	Personal Digital Assistant
PDU	*Protocol Data Unit*
PHB	*Per-Hop Behavior*
PLRT	Probabilistic Link Reliable Time
QAMACF	QoS-Aware transmission for Multimedia applications using Ant Colony with Fuzzy optimization
QoS	Quality of Service
RBP	Residual Battery Power
RIP	Routing Information Protocol
RREQ	Route Request
RSP	Route Selection Probability
RSVP	*Resource reservation Protocol*
RT	Routing Table
SHAR	Sharp Hybrid Adaptive Routing Protocol
SLA	Service Level Agreement
SSR	Signal Stability Routing
STAR	Source Tree Adaptive Routing
TCL	Tool Control Language
TCP/IP	Transmission Control Protocol/Internet Protocol
TORA	Temporally-Ordered Routing Algorithm
TOS	Type of Service
UDP	*User Datagram Protocol*
VANET	Vehicular Ad hoc Network
WANET	Wireless Ad hoc Network
WI-FI	Wireless Fidelity
WLAN	Wireless Local Area Network
WMN	Wireless Mesh Network
WRP	Wireless Routing Protocol

ZHLS	Zone-based Hierarchical Link State Routing Protocol
ZRP	Zone Routing Protocol

CHAPTER 1

INTRODUCTION

In today's world of technology, networking is playing important roles in the realms of business, education, research, e-commerce, communication, military, access to remote information, interactive entertainment, etc. Two types of deployable networks are currently availablenamely wired and wireless networks. Wired networks interconnect devices using cables while wireless networks enable communication between various devices using radiolinks whichcan be achieved either locally or globally. Both wired and wireless networks enable users to connect to the global Internet.

Compared to wired networks, wireless communication provides various advantages as the wireless devicesdo not need cables to communicatethereby enabling theusers(for instance, mobile users)tofreely exchange information while roaming, easy file sharing and transfer operations, etc. A wireless ad hoc network represents any type of computer networkwhose topology does not rely on any pre-existing infrastructure. It is a decentralized type of wireless network as it is not managed by routers or access points. This type of wireless network can be classified according to its applications as Wireless Mesh Networks (WMN), SENSOR networksandMobile Ad hoc Networks (MANETs).

A wireless mesh network, primarily a form of wireless ad hoc networkis made up of radio nodes organized in amesh like a topology and often consists of mesh clients, mesh routers, and gateways. Similarly, awireless sensor network monitors physical and environmental conditions by using autonomous and distributed sensorswhere each node is connected to one or more sensors. On the other hand, Mobile Ad hoc Networks (MANETs) represent a system of wireless nodeswhich can freely self-organize into a temporary highly dynamic and infrastructureless mobile wireless network.

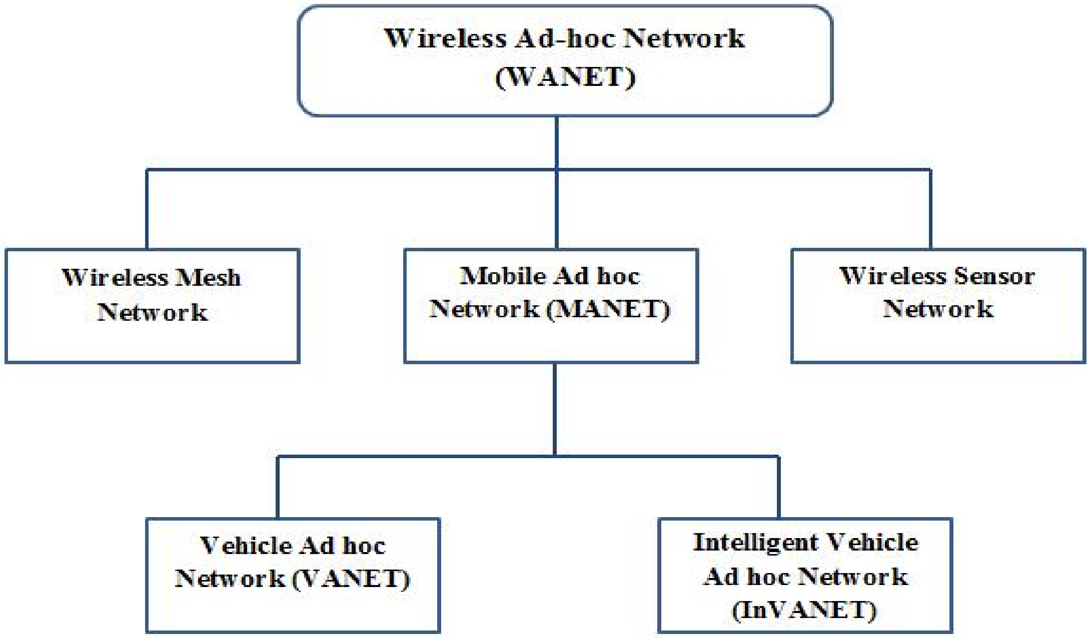


Figure 1.1 Types of Wireless Ad hoc Networks

Figure 1.1 presents different types of wireless ad hoc networks. Thoughall these networks almost share the same objective of providing services to mobile users without requiring cable connections,they differ in their approaches and performances. Interestingly, MANETs have proven to provide numerous advantages compared to other wireless networks. Developing a self-organizing network such as MANET,decreases the communication cost, improves flexibility, provides robustness, and favors its deploymentanywhere atanytime (Marcel and Vetrivelan, 2015).

1.1 INTRODUCTION TO MANETs

MANET is a collection of mobile nodes interconnected by auto-configured wireless links; mobile nodes can be any wireless terminal such as cell phones, Personal Digital Assistants (PDAs), tablets, portable gaming devices, etc. The network is decentralized implyingthat no central manager such as a router, an access point, or any network management-capable device is requiredfor controlling the whole network duringtopology formation operations, packets transmission, or any other network operations, thereby leading to frequent network topology changes. Nevertheless, MANETs haveseveral limitationssuch aslimited bandwidth, routing overhead, hidden terminal problems, battery and application-related constraints, dynamic route changes, resource constraints, nodecooperation-related problems, etc. Emergency communications namelymilitary battlefields, commercial sectors, tragic events such as floods and earthquakes requiring immediate attention, local access to conference rooms/classrooms, and Personal Area Networks (PANs) use MANETs as their preferred wireless network (Hoebekeet al.(2004)).

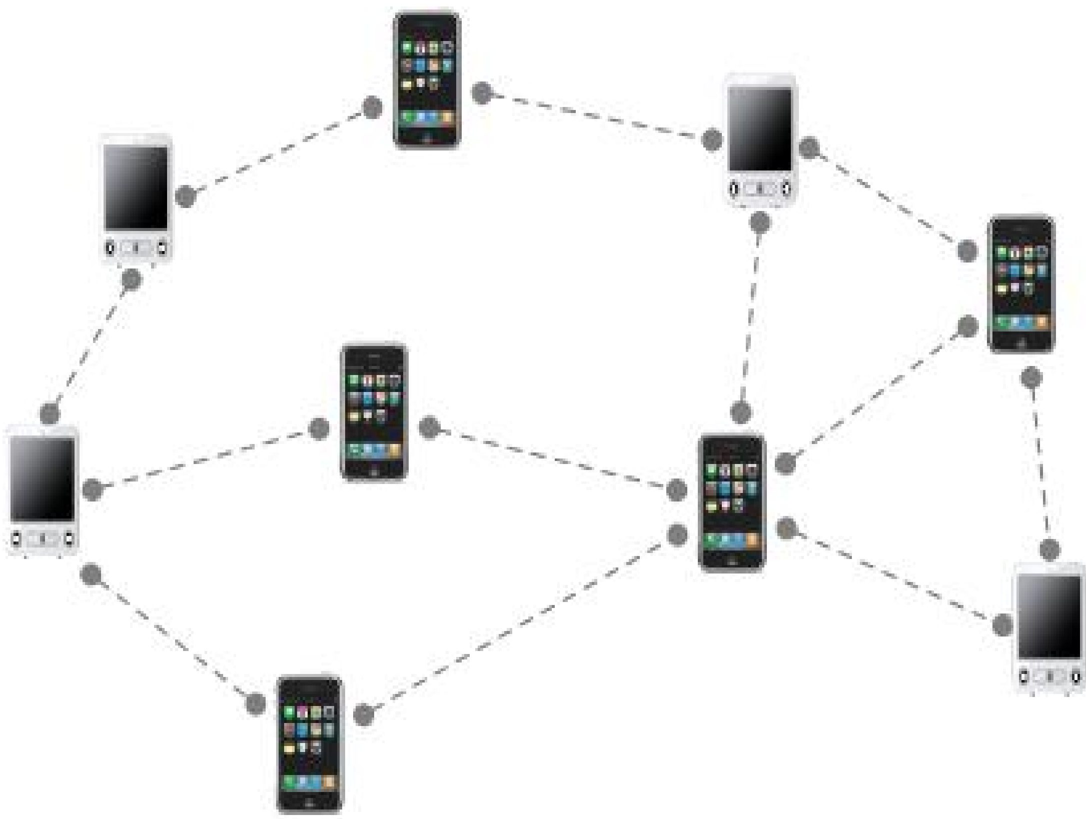


Figure 1.2 Mobile Ad hoc Network Architecture

Figure 1.2shows the basic architecture of MANET where mobile nodes (mobile phonesandPDAs) are wirelessly interconnected. The prominent features of MANET includemulti-hop routing, dynamic topology, and distributed organization.These features make MANET an excellent wireless network for the emergency situationsas previously mentioned. It is also very useful in commercial environments such ascollaborative works in business and private networks.

1.1.1 Intrinsic Characteristics of MANET

- *Distributed Architecture:* MANET is a distributed network as there is no specialized background network for the central control of network operations. Mobile nodes freely and randomly communicate without any management agent available.
- *Multi-hop Routing:* When a node tries to send information to another mobile nodewhich is out of its coverage area, packets should be sent through more than one intermediate node.
- *Autonomous Terminal:* Mobile devices in MANET act as independent nodeswhich function as both router and normal hosts.
- *Resource Utilization:* Being both a dynamic and distributed wireless network, it is not easy to predetermine the resource utilization by nodes.
- *Dynamic Topology:* Nodes randomly and freely move at any momentum speed to any direction. They are also able to join and leave the network at any time; this often results in frequent topological changes.
- *Multipath Routing:* This technique aims at using multiple alternative paths in MANETs. Using multiple paths provides various advantages over single-path routing such as fault tolerance, increased bandwidth, and improved security.
- *Lightweight Terminals:* In some cases, mobile nodes in MANETs are equipped with low CPU capability, low power storage, and less memory size.
- *Shared Physical Medium*: Any wireless devicewhose equipment is appropriate, is eligible to access the physical medium without restrictions.
- *Flexible Network Architecture:* Provides an efficient communication between nodeswith limited wireless connectivity range in case of minimum resource constraints.
- *Protocol Diversity*: In MANETs, mobile nodes can use different types of protocols such asBluetooth, GSM, TCP/IP, Zigbee, 802.11, and IrDA, etc. (Aarti and Tyagi (2013))

1.1.2 Challenges in MANET

- *Limited Bandwidth:* MANETs use the wireless link with a lower capacity, which continuously reduces the performance of QoS than in the infrastructure networks. The throughput of wireless communication is monitored after the process of fading, interference events, noise, multiple accesses, etc. This often results in low bandwidth, high bit errors, unstable and asymmetric links. So far, the optimal usage of bandwidth is necessary to keep the overhead of any protocol designed for MANETs as low as possible.

- *Multi-hop Routing Overhead:* Mobile nodes sometimes communicate with other nodes, which are in the out of coverage region. In such situations, generating routes in the routing table is quite difficultwhich leads to routing overhead.
- *Dynamic Topology*: Reliability between participating nodes in the wireless network is essential. However, sometimes it is not possible to achieve this as the trust relationship may be disturbed due to the dynamic topology membership in MANETs.
- *Packet Loss:* Packet loss is mainly due to the packet transmission errors. In most cases, wireless ad hoc networks may lead to high packet loss due to various factors such as collision events, hidden terminals, interference, unidirectional links, frequent path breaks, etc.
- *Hidden Terminal Problem:* Collision of the packets at the receiving node is called a hidden terminal problem, which is mainly due to the simultaneous transmission of those nodes that are not within the direct communication range of senders in spite of within the transmission range of the receiver.
- *Mobility Induced Route Changes:* MANET topology is highly dynamic due to the fast moving nodes. This often leads to both frequent path and route breaks.
- *Power Constraints*: Nodes are battery-powered, for maintaining their portability, size, and weights; those devices have to undergo some power resource restrictions.
- *Security Problem:* Mobile Ad hoc Networks using wireless radios are basically exposed to numerous security attacks such aseavesdropping, impersonation, routing attacks, black hole attack, wormhole attack, reply attack, jamming, man-in-the-middle attack, etc. (Aarti and Tyagi (2013))

1.1.3 Attacksin MANET

Understanding the possible form of attacks in MANETs is a highly challenging issue. There are numerous security breaches that affect this kind of wireless network. These attacks affect the entire network by disturbing secure transmission achievements (Aarti and Tyagi (2013)).

MANET attacks are as follows:

- *Black-hole attack:* A black hole attack is a routing attack aiming at blocking the propagation of routing information at a reliable mobile node by disturbing the packet delivery at a predefined path. A malicious node sends duplicate routing information claiming that it has an optimum route to the destination node. The sender then sends data packets passing through this unreliable node, as a result, all data packets are consumed or lost at the malicious node.
- *Wormhole Attack:* With this attack, the attacker captures packets at any given location and retransmits those data to another distant node which in turn, may distribute them locally. This attack can be launched by a malicious nodewhich does not have the knowledge of the attacked network by compromising the reliable nodes or cryptographic schemes.
- *Byzantine Attack*: This form of attack is concerned withthe security threatswhere an adversary (malicious node) has a full control of an authenticated node and can perform arbitrary activities to disrupt the system.
- *Snooping Attack:* This attack consists of accessing other nodes' packets without permission since MANET packets are transmitted onthe hop by hop routing basis, any intermediate malicious node can capture them during their transmission.
- *Resource Consumption Attack:* This form of attack is one of the Denial of Service (DoS) attacks; the intruder continually broadcasts the Route Requests (RREQ) packets throughout the network aiming at degrading the overall network performance as those operations consume a lot of network resources.

1.1.4 Routing Protocols in MANET

The main objective of deploying a network is relaying data from one end to another. Routing is the process of moving a data packet from the source node to the destination one by traversing various intermediate nodes. A number of routing protocols have been designed and implemented for MANETswhich are categorized into three different types according to their functionalities: proactive, reactive, and hybrid routing protocols (Dhenakaran and Parvathavarthini (2013); Aggarwal et al.(2011)).

Proactive Protocols (Table-Driven):

- Proactive routing protocols maintain the network topology information in the form of the routing table at every node, thus, keeping routes from each participating node to all the other nodes in the networks while also considering those nodes to which packets are not to be sent. They use both link-state and distance-vector approaches.

Reactive Protocol (Source Initiated On-Demand Driven):

- Routing protocols are reactive in that they do not maintain network topology information; necessary paths are found when required.
- These routing protocols eliminate the conventional routing tables and consequentlyreduce the need for updating these tables to track changes in the network topology.

Hybrid Protocols:

- Hybrid protocols combine the best features of both proactive and reactive protocols.
- These protocols aggregate a set of nodes into zones in the network topology. To route packets between different zones, the reactive approach is used.

Some other popular routing protocols in MANET include Temporally-Ordered Routing Algorithm [TORA] (Park. V. D and Corson. M. S (2001)), Wireless Routing Protocol [WRP] (Murphy. S and Aceves. G. L. J. J (1996)), Cluster Gateway Switch Routing Protocol [CGSR] (Anupama. M and Sathyanarayana. B (2011)), Hierarchical State Routing Protocol [HSRP] (Kumar. R. M and Geethanjali. N (2013)), Source Tree Adaptive Routing [STAR] (Paul. H and Das. P (2012)), Cluster-Based Routing Protocol [CBRP] (Kumar and Geethanjali (2013)), etc.

Table 1.1 Routing protocols in MANET

Category	**Representative Protocols**
Table-Driven Routing	OLSR (Optimized Link State Routing), BABEL, DSDV (Destination-Sequenced Distance-Vector), etc.
On-Demand Routing	ABR (Associativity-Based Routing), AODV (Ad hoc On-demand Distance Vector), DSR (Dynamic Source Routing), etc.
Hybrid Routing	ZRP (Zone Routing Protocol), ZHLS (Zone-based Hierarchical Link State Routing Protocol), etc.

Common requirements for routing protocols in MANET are provided below:

- Minimum Route Acquisition Delay
- Loop-free Routing
- Scalability of MANETs
- QoS provisioning
- Security
- Support for real-time sensitive traffics
- Quick Route Reconfiguration
- Minimum Control Overhead
- Unidirectional Link support
- Sleep period operations
- Demand-based operations
- Proactive operations, etc.

MANET Protocol Stack:

In this section, MANET protocol stack is discussed.

Application and Service Layer:

The application and service layer is the first layer in this layered architecture. It deals with the partitioning of tasks between fixed and mobile nodes as well as the Quality of Service (QoS) management issues.

Physical Layer:

The first standard for Wireless Local Area Networks (WLAN) was named IEEE802.11. This was released in1997 by the IEEE 802.11 standards. It providesspecifications for the media access control layers and physical layers ofWLAN. Following are the successors of the first standard i.e. the IEEE 802.11 extensions:

- IEEE 802.11a
- IEEE 802.11b
- IEEE 802.11e
- IEEE 802.11g

These standards focus on achieving higher data rates and enhance the Quality of Service (QoS) for real-time applications. In general, the IEEE 802.11 standard supports two modes for WLAN i.e. infrastructureless (ad hoc network) and infrastructure-based network topologies.

The major functions and services performed at the physical layer are character encoding, modulation, transmission, reception, and decoding operations. The IEEE 802.11 standard supports three physical layer technologies namelyDirect Sequence Spread Spectrum (DSSS), Diffused Infrared (DFIR), and Frequency Hopping Spread Spectrum (FHSS). DSSS uses the radio frequencies ranging from 2.4 to 2.4835 MHz. It uses Differential Binary Shift Keying (DBPSK) and Differential Quadruple Phase Shift Keying (DQPSK) modulations. FHSS uses the frequencies ranging between 2.4 GHz and 2.4835 and a bandwidth of 83.5 MHz. It employs 2 and 4 levels of frequency shift keying and divides the total bandwidth into 79 channels of 1MHz. DFIR utilizes wavelengths ranging from 850 to 950 nm engagingthe pulse position modulation technique.

Data Link Layer:

The data link layer is divided into two sub-layers; Logical Link Control (LLC) and Medium Access Control (MAC). LLC provides a way for the upper layers to deal with services at the MAC layer. This layer makes the IEEE 802.11 standard accessible to higher layers, a wired IEEE 802 LAN, for example. MAC layer protocols for wireless networks specify how nodes coordinate their communication over a common broadcast channel link. These protocols allowthe wireless nodes to share their communication channelsin stable, efficient, and fairmeans. PDU (Protocol Data Unit) addressing, channel allocation, frame formatting, error checking and fragmentation, and reassembling are the typical tasks of MAC protocols. It is also the responsibility of the MAC layer to overcome problems of the hidden terminal and resolve packet collision events between the nodes and it may also provide error correction operations during packet transmission at the physical layer.

MAC Layer:

It enables the transmission of MAC frames through the use of the physical channel. Thethree frame types includecontrol, management, and data. Management frames facilitate synchronization, authentication, timing, and deauthentication. Data frames are involved in the transmission of data, and control frames are exploited for both acknowledgement and handshaking operations.

MAC Layer offers two different types of services namely contention services and contention-free services. Contention services are provided when each node has a frame to transmit the contents to access the channel andthis mechanism is known asDistributed Coordination Function (DCF) while a contention-free service is referred asPoint Coordination Function (PCF). PCF is based on the polling scheme indicatingthat a point coordinator that continuously polls stations to offerthem the opportunity to transmit data is being used. PCF cannot be used in the ad hoc mode of operation and its setup for wireless devices is optional. DCF is the fundamental access method in IEEE 802.11 MAC protocol for data transmission. This is based on theCarrier Sense Multiple Access with Collision Avoidance (CSMA/CA) scheme. DCF is the only service operating in the ad hoc mode.

Network Layer:

The purpose of the network layer is establishing a connection between two nodes in a MANET. The routing protocols at the network layer should discover routes between them. Designing an efficient routing protocol and performing perfect routing operations in MANETs is a very challenging issue, this is mainly due to the lack of infrastructure and bandwidth recourses in MANET. For the packet transmission purposes, routes should be equipped with minimum bandwidth consumption and minimum overhead incurrence. Routing protocols i.e. reactive and proactive operate at this layer.

Transport Layer:

The transport layer provides end-to-end communication services for real-time applications. These convenient services include connection-oriented data stream support, error control, flow control, multiplexing, and congestion control. The most common transport layer protocols are Transmission Control Protocol [TCP] and User Datagram Protocol [UDP].

TCP is a connection-oriented transport protocol that provides the essential flow and congestion control mechanisms required to ensure reliable packet delivery. To use the network bandwidth efficiently and control the flow of packets in the network, TCP uses some mechanisms such assliding window and congestion control. The sliding window allows the source node to send multiple packets and then waits for an acknowledgement.

UDP is a simple connectionless protocol which provides the best effort service to transfer messages between nodes. It is not a reliable protocol since it does not incureither error or flow control mechanisms. This protocol is basically an interface between the application and network layers. It is mainly designed for applications for which extensive control features are not necessary such as streaming audio and video applications.

TCP congestion mechanisms prevent a sender from overrunning the capacity of the network. To avoid congestion in the network, TCP maintains a congestion window which restricts the amount of data sent. Several congestion control mechanisms, as well as their enhancements, have been proposed for the TCP over years. TCP congestion control mechanisms consist of four algorithms namely slow start, fast retransmit, congestion avoidance, and fast recovery.

TCP provides a reliable end-to-end data transfer using a technique known aspositive acknowledgement with retransmission. It assigns a sequence number for each byte that needs to be transmitted and expects a positive acknowledgement from the receiver. For each packet sent, the sender starts a retransmission. If the positive acknowledgement is not received and the timer expires, then the packet is retransmitted.

In general, TCP was initially designed to work in wired networks where a huge number of packets are lost due to congestion events. Hence, it uses a packet loss as an indication of the network congestion and deals with iteffectively by making a corresponding transmission adjustment to its congestion window. However, MANETs suffer from several other types of packet losses such as, those occurring due to excessive noise, interference, lack of power, signal loss, the collision of the packets, and frequent route failureswhich emergedue to high node mobility. For this reason, TCP is not well suited for wireless networks, especially for MANETs.

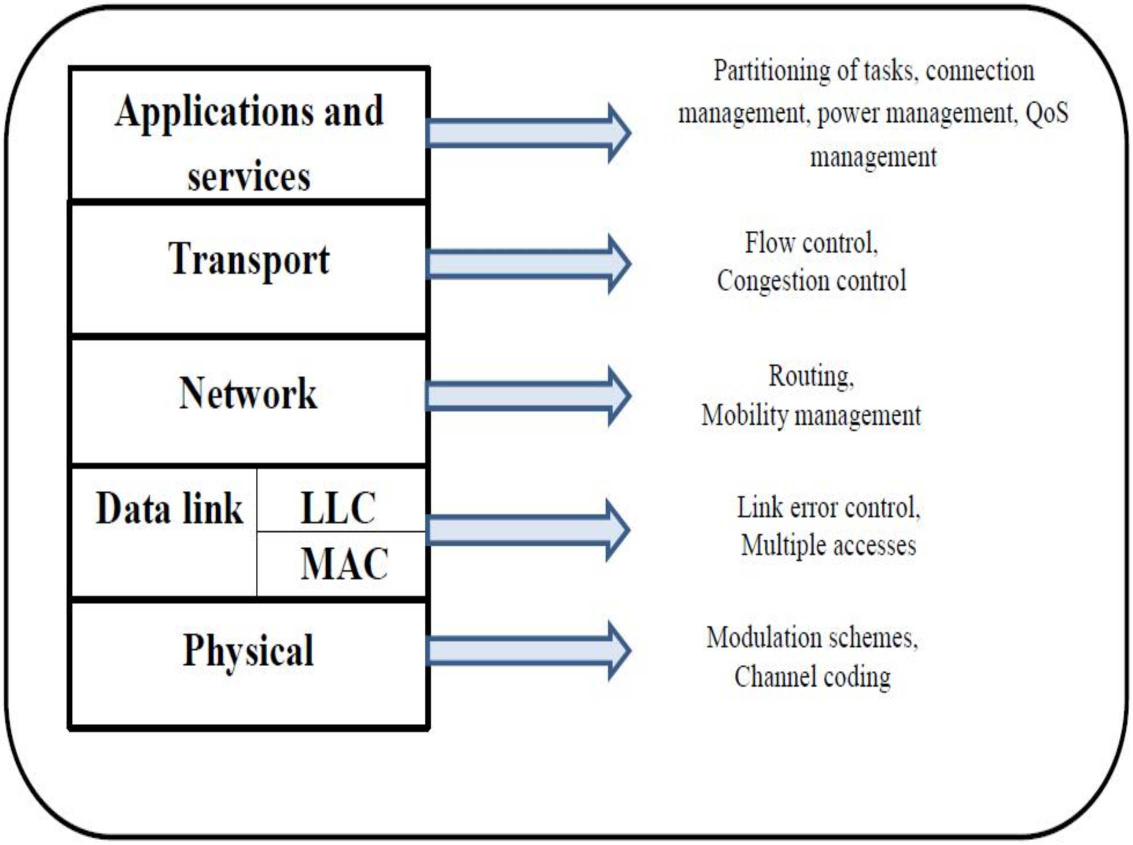


Figure 1.3 MANET Protocol Stack

1.1.5 Quality ofService (QoS) in MANET

Quality of Service is usually defined as a set of service requirements that need to be met by the network while transporting a stream of data from one end to another. The network needs are governed by the service requirements of end-user applications and the network is expected to guarantee those services to the end-user in terms of the best network performance such as bothreduced end-to-end delays andprobability of packet loss, and increased bandwidth and throughput, etc. Power consumption is yet another issue to be taken into consideration.

The Quality of Service features in Mobile Ad hoc Networks:

- *QoS models:* Specify an architecture in which some kinds of services could be provided to users. The model includes QoS resources reservation signaling, QoS routing, and QoS Medium Access Control (MAC).

- *QoS Adaptation:* This feature hides all the environment-related features from awareness of the multimedia application and provides an interface for applications to interact with QoS control.
- *QoS signaling:* It acts as a control center in QoS support. The functionality of QoS signaling is determined by the QoS model and works above the network layer.
- *QoS routing*: It is a part of the network layer and searches for a path with enough resources but does not reserve resources.
- *QoS MAC protocols:* These are essential components in QoS for MANETs. QoS supporting components at the upper layers such asQoS signaling or QoS routing assume the existence of a MAC protocolwhich solves the problems of medium contention, supports communication and provides resource reservation.

QoS Layered Architecture:

The layered view/architecture of Quality of Service contains three parts:

- User
- Application layer
- Network layer

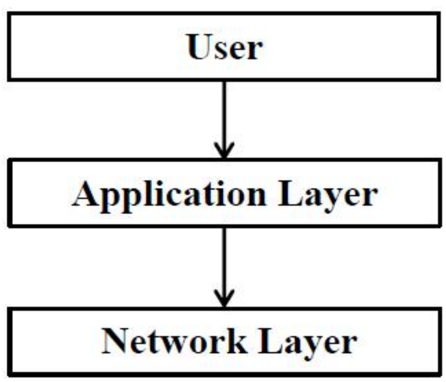


Figure 1.4 Layered Architecture of Quality Of Service

Application Layer:

This layer explains how well user expectations are qualitatively and quantitatively satisfied such asclear voice, jitter-free video, etc. It describes the arrival pattern and sensitivity to delivery delays, end-to-end protocols, application-specific representations, and encoding.

Network Layer:

This layer describes four quality factors:

- Jitter- the variation in latency
- Packet loss- the percentage of lost data
- Bandwidth- the rate at which the application traffic is carried out by the network
- Latency- the tolerable delay during data delivery processes.

Constraints in MANET QoS:

The QoS requirement of an application is defined as a set of constraints which can be either link constraints or path constraints. A link constraint specifies the restriction on the use of links and a path constraint specifies the end-to-end QoS requirement on a single path. Each link is associated with multiple parameters in the network that can be classified into additive and non-additive constraints.

- Additive constraints: E.g. cost, delay, and delay variation
- Concave constraints/convex constraints/frequency constraints: E.g. bandwidth
- Multiplicative constraints: E.g. loss probability
- Space constraints: E.g. system buffer
- Reliability constraints: E.g. error rate.

Challenges for MANET QoS provision:

- *Dynamic network topology:* A QoS session may suffer due to frequent path breaks, thereby requiring re-establishment of new paths. The delay incurred while re-establishing a QoS session may cause some of the packets belonging to that session to miss their delay targets and/or deadlineswhich is not acceptable for applications that have stringent QoS requirements.
- *Error-prone wireless channel:* The wireless radio channel by nature is a broadcast medium. The radiowaves suffer from several impairments such as attenuation, thermal noise, interference, shadowing, and multipath fading effects during propagation through the wireless medium. Thus, it becomes difficult to ensure the QoS commitments such ashard packet delivery ratio or link longevity guarantees.

- *Lack of central coordination:* Being infrastructureless, it is not easy for protocols specialized in providing high Quality of Service to achieve their goals as various eventswhich should be centrally controlled will fail.
- *Imprecise state information:* Due to dynamic changes in network topology and channel characteristics, the state information such asbandwidth, delay, jitter, loss rate, etc. are inherently imprecise. This may lead to inaccurate routing decisions resulting in some packets missing their deadlines, leading to violations of real-time QoS commitment.
- *Limited availability of resources:* As previously mentioned, MANET's mobile devices generally have less computational power, less memory, and a limited battery power supplywhich primarily influencethe provision of QoS assurances.
- *Hidden Terminal Problem:* This problem occurs when packets originating from two or more sender nodeswhich are not within the direct transmission range of each othercollide at a common receiver node. It necessitates the retransmission of packetswhich may not be acceptable for flows that have strict QoS requirements (Parvez and Peer (2010)).

Quality of Service(QoS) routing:

QoS routing may be defined as "a routing process that guarantees to support a set of QoS parameters during the route establishment processes". The QoS routing in MANETs is only needed to support real-time multimedia communications such as video-on-demand, news-on-demand, web browsing, traveler information system, etc. These applications require a QoS guarantee not only over a single hopbut also over the entire multi-hop network. QoS routing supports both QoS-driven selection and QoS reporting mechanisms and provides path information at each router (Prasad and Zaheeruddin (2011)).

Types of Quality of Service models:

There are three types of services namely,

- Integrated Services (IntServ)
- Differentiated Services (DiffServ)
- Flexible Quality of Service Model for MANETs **(**FQMM)

Integrated Services:

An integrated service is a reservation-oriented method.This type of service provides the closest circuit emulation on IP networks. IntServ model merges the advantages of two different paradigms: datagram network and circuit switched networks. Resource reservation Protocol (RSVP) was proposed to set up and maintain the virtual connection. It is also used to propagate the attributes of data flow and to request resources along the path. Routers finally apply corresponding resource management schemes to support QoS specifications of the connection. Based on these mechanisms, IntServ provides quantitative QoS for every flow (Parvez and Peer (2010)).

Two types of services can be requested via RSVP (assuming all network devices support RSVP along the path from the source to the destination):

The first type is a very strict guaranteed service that provides firm bounds on end-to-end delay and assured bandwidth for traffic that conforms to the reserved specifications. The second type is a controlled load service that provides for a better than the best effort and low delay service under light to moderate network loads. It is possible (at least theoretically) to provide the requisite QoS for every flow in the network provided it is signaled using RSVP and the resources are available.

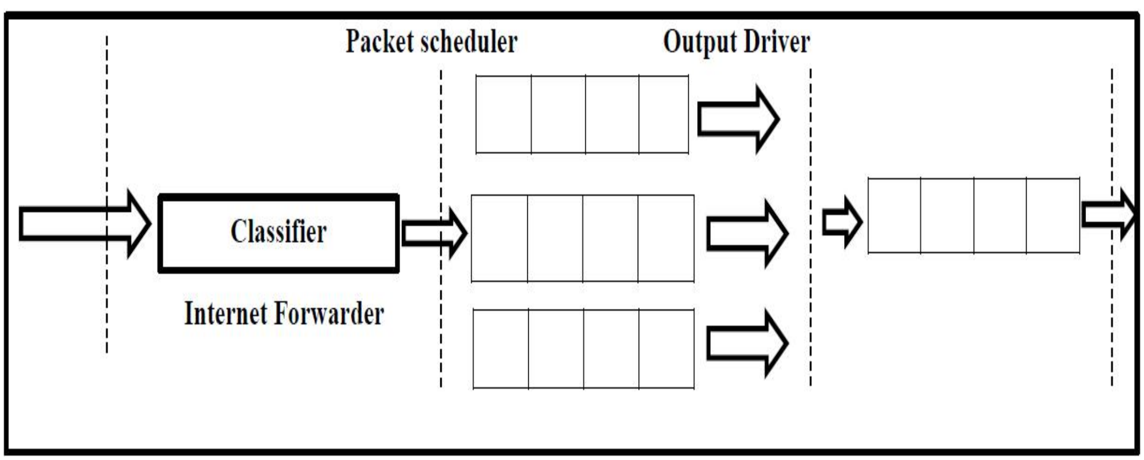


Figure 1.5 Intserv Architecture

IntServ has the following salient shortcomings in MANET environments:

- IntServ provides per-flow granularity, hence, the amount of state information increases proportionally with the number of flows.

- Scalability problem is less likely to occur in current MANETs due to the small number of flows, the limited size of the network, and the bandwidth of the wireless link.

Differentiated Services [DiffServ]:

DiffServ was mainly designed to overcome the difficulties which are dealt with the IntServ and the RSVP protocol and differs in the kind of service it provides. While IntServ provides per-flow guarantees, DiffServ follows the philosophy of mapping multiple flows into a few service levels. At the boundary of the network, traffic entering a network is classified, conditioned, and assigned to different behavior aggregates by marking a special DS (Differentiated Services) field in the IP packet header (TOS field in IPv4 or CLASS field in IPv6). Within the core of the network, packets are forwarded according to the per-hop behavior (PHB) associated with the DSCP (Differentiated Service Code Point). This eliminates the need to keep any flow state information elsewhere in the network (Parvez and Peer (2010)).

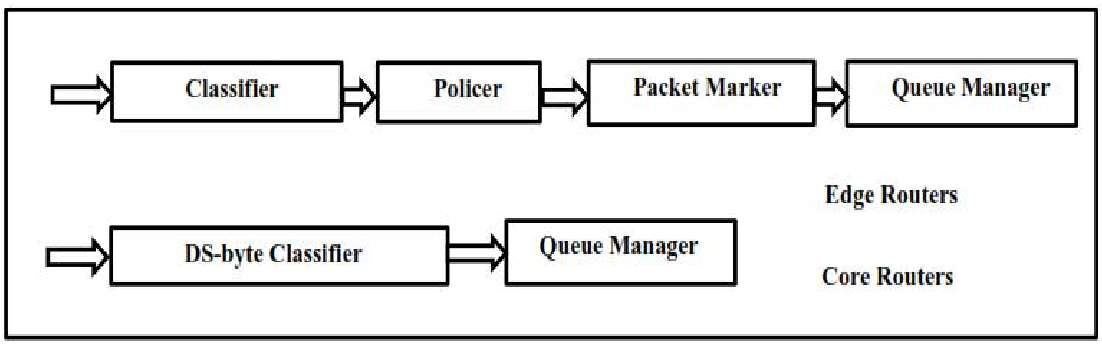


Figure 1.6 DiffServ Architecture

The major drawbacks of DiffServ in MANETs are listed below:

- **Soft-QoS Guaranteed:**

DiffServ uses a “Relative-Priority Scheme” to map the Quality of Service metrics to a service level. This aggregation result is more scalable and a more approximate service to user flow.

- **Service Level Agreement (SLA):**

Service Level Agreement is a kind of contract between a customer and the Internet Service Provider (ISP). Internet Service Provider specifies the forwarding service that the customer should receive. Moreover, the DiffServ boundary nodes are required to monitor the arriving traffic for each service class and to perform traffic classification and conditioning to enforce the negotiated SLAs.

- **Ambiguous core network:**

The benefit of differentiated service is that the traffic classification and conditioning have to be done only at the network boundary nodes. This feature makes QoS provisioning much easier in the core of the network. In MANETs, though there is no clear definition of which oneis the core, every node can act as a potential sender, receiver, and router. This drawback would again take us back to the IntServ modelwhere several separate flow states are maintained.

Table 1.2 Differences between IntServ and DiffServ according to the priority class

Priority Class	IntServ	DiffServ
1st class e.g. voice, low delay	Guaranteed	Expedited For-warding
2nd class e.g. video, high throughput	Controlled Load	Assured Forward-ing
3rd class e.g. data, no constraint	BE	BE

Table 1.3 Differences between IntServ and DiffServ according to criteria

Criteria	IntServ	DiffServ
Granularity	Individual flow	Aggregate of flows
State in routers	Per-flow	Per-aggregate
Classification	Header fields	DS field
Signaling	Required(RSVP)	Not required
Coordination	End-to-end	Per-hop
Scalability	< # of flows	< # of classes

Flexible Quality of Service Model for MANETs[FQMM]:

FQMMcombines both IntServ and DiffServ models. In this model, three kinds of nodes are defined namely ingress, egress, and interior nodes. An ingress node is a mobile node that sends data. An egress node is a destination node and interior nodes are the nodes forwarding data to other nodes.

FQMM tries to preserve per-flow granularity for a small portion of traffic in MANET given that a large amount of traffic belongs to the per-aggregate of flows i.e. per-class granularity. A traffic conditioner is placed at the ingress nodeswhere the traffic originates and is responsible for marking or discarding packets according to the traffic profilewhich describes the temporal properties of the traffic stream such astransmission rate and burst size (Parvez and Peern (2010)).

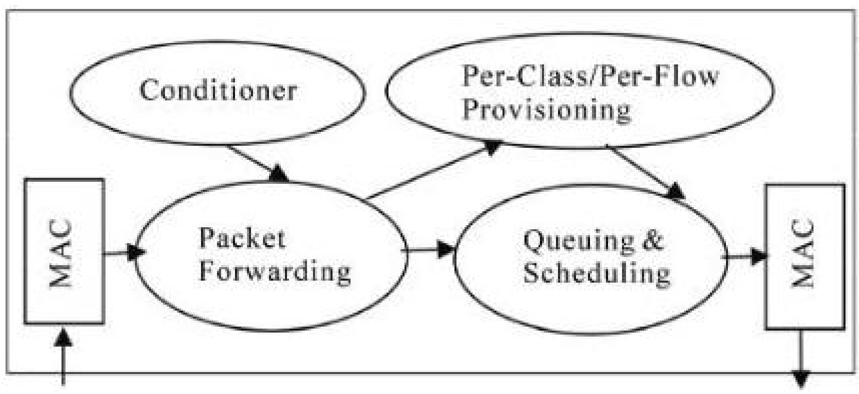


Figure 1.7 FQMM Architecture

FQMM suffers from the following problems:

- FQMM aims at tackling the scalability problem of IntServ and without an explicit control on the number of services with per-flow granularity. However, theproblem still exists.
- Due to DiffServ behaviors in ingress nodes, FQMM model may not be able to satisfy the hard QoS requirements.

QOS routing protocols in MANETs:

QoS-aware routing protocols are used to determine an efficient path from a source node to a destination nodethatsatisfies the Quality of Service provision constraints.The QoS-aware path is determined within the constraints of bandwidth, minimal search, distance, and traffic conditions. Since the path selection criterion is based on the desired QoS, the routing protocol can be termed as QoS-aware (Asokan andNatarajan (2008)).

Secure routing for acquiring high QoS:

Concerning the QoS provision, security issues should not be neglected as they play an important role in determining the level of the QoS provision in MANETs. Security breaches affect the performance of MANETs related to confidentiality, integrity, authentication, availability, fairness, lack of source control, anonymity, resilience against path hijacking, non-source based routing, and privacy.

QoS Evaluation Parameter Metrics:

Various parameter metrics are available in the literature toevaluate the performance of MANETs in term of QoS provision measurements. Some examples of such parameters are the end-to-end delay, jitter, the available bandwidth, and the probability of packet loss.Therefore, various routing protocols aiming at providing the QoS in MANETs have been proposed inthe literature by different researchers (Patel and Reddy (2013)).

Table 1.4 QoS Evaluation Parameter Metrics

Throughput	The rate of successful message delivery over a communication channel.
Delay	This parameter is intrinsic to communication. Since the end-points are distant and the information will consume some time to reach the other side. Delay is also called latency.
Jitter	Jitter is variation in delay of the received packet. It is also called packet delay variation (PDV). The difference in end-to-end one-way delay between selected packets in a flow with any lost packets being ignored.

Packet Loss	Occurs when one or more packets of data being transported across the Internet or a computer network fail to reach their destination.
Service Level Agreement	Defines in a customer friendly manner, tangible and easy constraints to be observed and proven, the expectationsfor all the involved parties in the delivery of the service.
Reliability	A reliable packet transmission consists of transferring packets with minimum delay and packet loss.
Resource Management	Fairly and efficiently using the available resources.
Power Consumption	The amount of power consumed while communicating during the overall operations of MANETs.
Packet Delivery Rates	The Rate at which packets are delivered.
Mean Opinion Score	MOS is a test that has been used for decades in telephony networks to obtain the human user's view of the quality of the network.

1.1.6 Advantages of Mobile Ad hoc Networks

Despite some challenges faced, MANETs provide a number of advantages:

(a) *Low cost of deployment*: As the name suggests, ad hoc networks can be deployed on the fly, thus, requiring no expensive infrastructure such ascopper wires, data cables, etc.

(b) *Fast deployment*: Compared to WLANs, ad hoc networks are very convenient and easy to deploy as they require less manual intervention since there are no cables involved.

(c) *Dynamic configuration:* Ad hoc network configurations can dynamically change over time. This topological dynamicity is advantageous for data sharing purposes.

1.1.7 Applications of Mobile Ad hoc Networks

Ad hoc networks endow several interesting applications ranging fromthe battlefields to classrooms. In this section, some areas of deployment are discussed.

(a) *Battlefields*: Communication achievements between soldiers and vehicles can be carried out using this kind of ad hoc networks using handheld devices. The vehicle mounted-devices can be equipped with power sources for “recharging” these mobile devices.

(b) *Rescue Operations*: In scenarios such asfirefighting or avalanche rescue operations, a quick deployment of a wireless network is urgently required. Ad hoc networks can be used in such events aiming at providing an efficient communication between the firefighters.

(c) *Event Coverage*: Scenarios such aspress conferences might entail reporters to share data with their mates. In such cases, multimedia traffic can be exchanged between various handheld devices such aslaptops, tablets, PDAs, etc.

(d) *Classroom*: In a classroom, students and their respective instructors can set up an ad hoc wireless network to share data using various wireless devices.

1.1.8 Real-time Multimedia Applications

Data carried by the networking applications such as the web, file transfer, and electronic mail, is, for the most part, static content such astext and images. When static content is sent from one host to another, it is desirable for the content to arrive at the destination as soon as possible. Nevertheless, moderately long end-to-end delays, upto tens of seconds, are often tolerated for static contents.

Multimedia is a term that describes multiple forms of information including audio, video, graphics, animation, images, text, etc. The best examples are continuous media such as animation, audio, and video that are time-based, i.e., each audio sample or video frame has a timestamp associated with itrepresenting its presentation time. Multimedia data has to be presented in a continuous fashionin accordance with their associated timestamps. For example, a video is typically rendered at 30 frames per second to provide the viewers the illusion of smooth motion. As a result, multimedia applications typically have the real-time constraint i.e., media data have to be delivered and rendered in real-time.

Today, with the advances in digital media and networking technologies, multimedia has become an indispensable feature on the Internet. Animation, audio,and video clips are becoming verypopular on the Internet. A large number of distributed multimedia applications have been createdincluding Internet telephony, Internet videoconferencing, Internet collaboration(combines video, audio,and whiteboard), Internet TV, on-demand streaming or broadcasting, distance learning, distributed simulation, entertainment, andgaming.

Multimedia Data Characteristics:

- Multimedia applications usually require much higher bandwidth than traditional textual applications.
- Most multimedia applications have stringent delay constraintsincluding real-time delivery.
- Multimedia data stream is usually bursty due to the dynamics of different segments of the media.
- Other characteristics of multimedia data include power-hungry, synchronous, loss-tolerant, having components of different importance, highly adaptable, etc. Some of the characteristics such asloss-tolerance, prioritized components, and adaptability can, in fact, be exploited in a real-time multimedia communication system.

Real-Time Networked Multimedia:

Real-time multimedia can be broadly classified into interactive multimedia and streaming media.

- Interactive multimedia applications includeInternet telephony, Internet videoconferencing, Internet collaboration, Internet gaming, etc. In interactive multimedia applications, the delay constraint is very stringent in order to achieve interactivity. For example, in Internet telephony, human beings can tolerate only a latency of about 250 milliseconds. This imposes an extremely challenging problem for interactive multimedia applications over the Internet that provides only the best effort service.
- The second class of networked multimedia technology is streaming media. Streaming media technology enables the real-time or on-demand distribution of audio, video, and multimedia on the Internet. Streaming media is the simultaneous transfer of digital media

so that it is received as a continuous real-time stream. Streamed data is transmitted by a server application, received, and rendered in real-time by client applications.

Real-time Stream Media protocols:

Real-time media delivery requires a maximum end-to-end delay to guarantee that live audio and video can be received and presented continuously. For this reason, underlying protocols other than TCP are typically used for streaming media.Since TCP is targeted for reliable transmission and frequent retransmission may violate the real-time delay constraint, TCP is not suitable for IP multicast. The most commonly used transport protocol for real-time streaming is the User Datagram Protocol (UDP). UDP is an unreliable protocol; it does not guarantee that there is no packet loss or packets havearrived in order. It is the higher layer's responsibility to recover from lost data, duplicated packets, and out of order packets (Rao and Hwang (1996)).

1.2 MOTIVATION

MANETs have been popular as they are advantageous for real-time applications which require communication using mobile wireless devices. Whatever may be the purpose of a MANET deployment, the targeted achievement is unique i.e. the transmission of data from one end to another. Information to be transmitted may be classified into two broader categories; ordinal and multimedia data. The former transmission type does not pose rigorous constraints compared to the latter one because multimedia data can be one of the different types of files such asvideo, audio, photo, image, thereby warrantingefficient techniques for achieving a successful transmission.This could be attributed towhy multimedia applications require very high QoS achievements.

Various challenges arise from the infrastructureless nature of MANETs such asQoS degradation during multimedia data transmissionwhich then results inthe reduction of the whole network performance. As various researches previously done todeal with this frequent issue have faced some difficulties, different techniques and protocols have been designedto providehigh QoS for this type of wireless network.

The major problem inMANET is related to its dynamic and unpartitioned large-sized topology which makes it hard-manageable. Clustering is one approach towards dealing with this MANET management-related problem as it divides the network into a small manageable group of nodes.Nonetheless, due to the unstable nature of MANET, it is sometimes difficult for protocols specialized in clustering techniques to divide the whole network into clusters in conjunction with their cluster head selection criterion.

The energy constraints are the other challenges faced as some nodes are dead due to their low battery powerwhich results in degradation of the whole network performance. Another problem is related to the broadcasting nature of some routing protocolswhich sometimes causes storm problems during the route discovery process. Due to the high mobility of some nodes, MANET faces various challenges during path discovery, route selection, and packet transmission processes.

Another major issue relates to the fairness often being neglected while transmitting the packets; a packet scheduling algorithm is required to minimize the routing delay, provide fairness between packets, and much more. The last issue is related to security breaches caused by malicious nodes; hence, an efficient intrusion detection scheme should be designed to prevent such nodes from participating in the overall network operations.

Different techniques have been proven to be effective in increasing the Quality of Service for real-time applications and in controlling all the above-mentioned inherent problems. These include multicast mechanisms, clustering schemes, power-aware routing, fairly packet transmission, security provision approaches, etc. For evaluation purposes, various QoS parameter metrics have also been proposed by various researchers such asend-to-end packet delivery ratio, end-to-end delay, throughput, route reliability, routing overhead, energy, normalized routing load, and average end-to-end delay. Unfortunately, none of those researches provides full support for high QoS provision during multimedia data transmission.

The motivation behind this study is to designand implement various algorithms based on previously mentioned techniques andaddress those aforementioned problems inhibiting the high Quality of Service provision for real-time applications in MANET.

1.3 OBJECTIVES

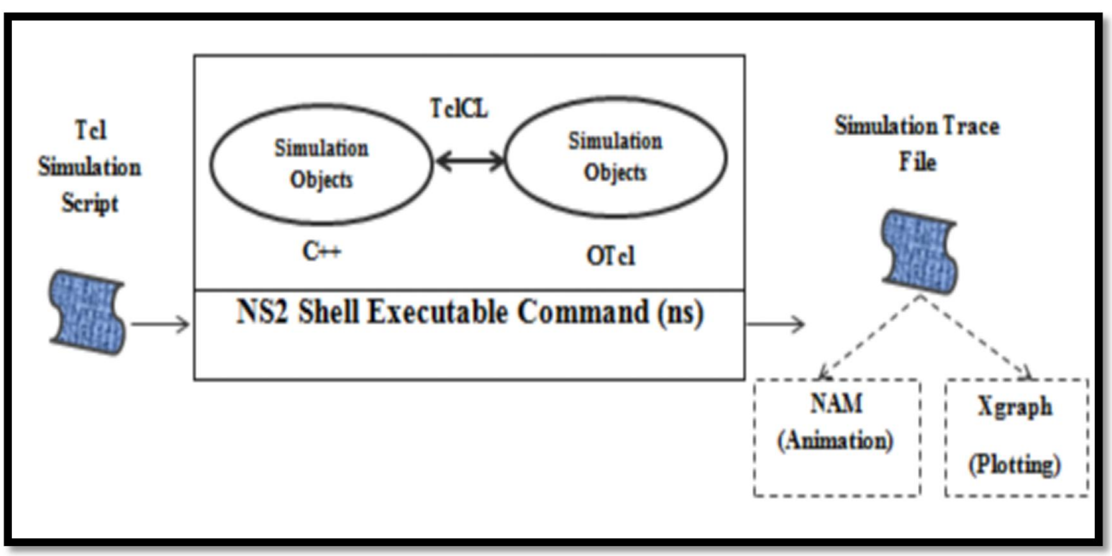
Our primary contributions in this research work involve applications of different QoS techniques to design and implement various robust routing protocols for acquiring high Quality of Service during multimedia data transmission.Each mechanism is a compound algorithm consisting of various QoS-provision techniques, each one addressing one of the negative issues affecting MANET performance. It has been proven that a singletechnique or algorithm is not enough to provide high Quality of Serviceespecially for real-time multimedia applications as such applications impose rigorous constraints to achieve the QoS. This research work mainly aims to:

- Describe various QoS routing metrics and protocols available for Mobile Ad hoc Networks.
- Survey different QoS provisioning techniques proposed for multimedia applications.
- Create analytical models for the proposed QoS routing schemes and study their performances in multimedia data reception probability based on information available at the nodes.
- Design and implement new improved multi-techniques, QoS-aware routing protocols capable of increasing the QoS in MANETs for successful transmission of multimedia data.
- Simulate dynamic Mobile Ad hoc Networks and analyze the experiments.
- Achieve high QoS during multimedia data transmission.

Tools Used:

The experimental evaluations are carried out using the NS-2 simulatorwhich is an object-oriented, event-driven, open-source network simulation tool that runs on Linux. It is a discrete event simulator targeted at networking research and provides substantial support for simulation of routing, multicast protocols, and IP protocolssuch as UDP, TCP, RTP, and SRM over wired and wireless (local and satellite) networks. This tool is written in C++ and OTcl.

Figure 1.8 NS-2 Architecture



1.4 ORGANIZATION OF THESIS

In this chapter, an introduction to MANETs namely their intrinsic characteristics, limitations, tracks, routing protocols, Quality of Service, advantages, and applications, viz.real-time multimedia applicationshave been discussed in detail.The motivation behind this research study along with its main objectives has also been emphasized in this introductory chapter.

In chapter 2, various works available in theliterature related to Quality of Service and the techniques used to achieve it have beenreviewed. Those techniques includeSwarm Intelligence mechanisms, Multicast and Broadcasting techniques, Genetic Algorithms, Packet Scheduling techniques, Network Lifetime Prediction routing, Security, and Network Clustering mechanisms.

Chapter 3discusses on QoS-Aware Transmission for Multimedia Applications Using Ant Colony with Fuzzy Optimization (QAMACF). It focuses on the design, implementation, and appraisal of the QoS framework that supports multimedia application in MANETs.The key basis of this mechanism is the Ant Colony with Fuzzy optimization technique.

Chapter 4 describes theQoS-Based Routing Approach Using Genetic Algorithms for Real-time Multimedia Applications.The proposed geneticalgorithm; GDAQM (Genetic with DPD for Attaining high QoS in MANET), a multicast routing protocolwhich is a combination of both the Genetic and Modified DPD-k (Dynamic Priority with Deadline Considerations) schemes has been discussed and the results obtained are presented.

Chapter 5 presents a Network Lifetime Prediction Secure Routing Algorithm Enhanced with Packet Scheduling Features, MARMAQS (Multi-Algorithm Routing for Acquiring high Quality of Service in MANET). The proposed scheme mainly aims at improving the provision of QoS in MANETs; this is achieved by enhancing various QoS parameters namelyincreased network lifetime, throughput, Packet Delivery Ratio (PDR), and reliability whileminimizing both end-to-end delay and routing overhead.

Chapter 6discusses an advanced clustering mechanism; FSR-CAES(Full-Featured Secure Routing Clustering Algorithm with Energy-Aware and Scheduling capabilities for increasing QoS in MANET).As its name suggests, is an efficient clustering techniquewhich consists of numerous algorithmseach one containing one of those negative issues affecting the whole network performance.

Chapter 7 provides a comparative study of the four proposed QoS schemes using the parameter metrics namelypacket delivery ratio, end-to-end delay, normalized routing loss, packet loss, routing overhead, energy, reliability, and throughput to prove which protocol performs better than others in increasing the Quality of Service for each parameter metricand varying number of nodes. Chapter 8 concludes our research work and presents the direction for future works.

CHAPTER 2

LITERATURE SURVEY

The Quality of Service considerations for efficient routing in Mobile Ad hoc Networks have come a long way in the past years and enabled the protocol designers to increase the satisfaction of MANET end-users. The first task carried out in this research was to study the relevant literature on two general areas of interest: Routing and Quality of Service provision techniques in MANET. The purpose was to become familiar with the MANET routing operations and understand various challenges faced and their effects on QoS provision. Some other researches onhigh QoS provision in MANETs have been carried out since the times of the surveys. Surveysconducted by Perkins and Hughes (2002), Reddy et al. (2006), Zhang and Mouftah (2005), Hanzo and Tafazolli (2007) have contributed a lot in this research field. It was apparent that there were only little works existent on achieving high QoS in MANETswhich take into account various issues affecting the QoS provision especially for real-time applications (Krishnan and Rajasekar (2012)).

It was discovered that most of theexisting solutions largely focus on supporting QoS using single techniques and there were doubts duringthe early years regarding those simple techniques used. A simple mechanism is not enough in providing solutions to numerous problems inhibiting QoS provision for real-time multimedia applications, this gap was identified through a critical reading and analysis of the literature. However, those techniques proved effective in increasing the Quality of Service when combined together. To date, studies on the QoS for multimedia data transmission problemsare still in progress but none of them is fully solved (Sutariya and Kamboj (2013)). At present, the field addresses critical problems faced by theusers during both ordinary and multimedia data transmission and due to the exponential growth in information exchange using MANETs, QoS provision techniques will play an important role in future. In this chapter, various works available in the literature related to different existing QoS provision techniques in MANETs have been reviewed. The literature was regularly reviewed throughout the duration of this researchwith newly published works taken into consideration wherever necessary.

2.1 QUALITY OF SERVICE

2.1.1 A Brief Overview

The Quality of Service provision is nowadays becoming more important and necessary for increasing MANET performancewhich is mainly due to the rising popularity of real-time applications. Since the past decades, mobile traffic refers to data generated by handsets, laptops, and mobile broadband gateways withits annual growth rate becoming more and more interesting.

According to a survey, Cisco mobile data rate in 2010 was triple the volume of the entire global Internet used in 2000. The growth rate in the previous year was 159% which has been 10% higher than thatpredicted in 2009. This rapid growth in mobile data means that there were huge mobile datawhich would be used in the following fiveyears with an average annual growth of 92%. There are several reasons why mobile traffic hasgrown so quickly. First of all, mobile video datawhich require high bit rates are considered to lead this mobile traffic growth. It was reported that mobile video reached as high as 49.8% of the total mobile traffic in 2010 andmobile traffic in 2015would be two-thirds. Moreover, the Internet gaming consumed an average of 63 PB per month in 2009. It was again revealed an expectation of an annual growth of 37% in the next five years to come and that Voice over IP (VoIP) including phone-based VoIP services, direct from or transported by a third party to a service provider and software-based Internet VoIP such as Skype have led to the increase in mobile traffic.Moreover, it was stated that those real-time applications would demand very high Quality of Service guarantee provisions (Patel and Gohil (2014)).

2.1.2 Background on Swarm Intelligence Mechanisms

Swarm Intelligence (SI) is a relatively new paradigm being applied in a host of research settings to improve the management and control of large numbers of interacting entities such as communication, computer and sensor networks, satellite constellations,and more. Attempts to take advantage of this paradigm and mimic the behavior of insect swarms, however, often lead to many different implementations of SI. The rather vague notions of what constitutes theself-organized behavior lead to rather ad hoc approaches that make it difficult to ascertain what SI is to assess its true potential and take full advantage of it (Fleischer (2003)).

Artificial intelligence techniques are nowadays involved in various applications. Several studies make use of Genetic Algorithm(GA)-based techniques to solve network problems. Particle Swarm Optimization (PSO) is a stochastic optimization technique developed by the inspiration of the social behavior of bird flocking or fish schooling. In PSO, every single solution is a 'bird' in the search space (particle). The strength value is combined with each particle which is calculated by the fitness function to be optimized and it includesvelocitywhich expresses the flying of the particle. The particles will fly in the search space and will adjust with the velocities dynamically according to their historical behaviors. This process will guide the particles to fly towardsa better search area in the search space. In MANET, the work of sending the packets from source to destination is difficult because of the mobility of nodes and there is no central control. To solve these problems, the swarm intelligence concept can be applied. The PSO algorithm was initially introduced in terms of social and cognitive behavior. This technique resolves different problems in various fields such asengineering and computer science (Manickavelu and Vaidyanathan (2014)).

1. A Formal Study on Ant Dynamic Source Routing Approach

For years, people realized the importance of achieving routing operations in a MANET but sometimes this achievement is challenging because of dynamic topology and lack of an existing fixed infrastructure. Despite those challenges, several robust protocols have been developed for ad hoc mobile networkswhich are capable of providing high throughput and packet delivery fraction and lowered end-to-end delay, delay jitter, normalized routing load, and energy. For example, AntNet, an adaptive routing algorithm inspired by ant colonies is able to solve routing problems in wired networksand is also advantageous in wireless networks.

Sofat andGupta (2013) implemented anAnt Colony Technique on the reactive routing protocol DSR. They proposed the Ant Dynamic Source Routing (Ant-DSR) schemewhich is a reactive protocol that implements a proactive route optimization method through the constant verification of cached routes. When AntNet algorithm is applied to DSR protocol, the performance metrics are improved. Mobile nodes are required to maintain route caches that contain the source routes of which the mobile node is aware. Entries in the route cache are continually updated as new routes are learnt. The protocol consists of two major phases: route discovery and route maintenance. In Ant-DSR (ADSR), the Forward ant (FANT) and Backward ant (BANT) packets are added in both route request and route reply of DSRrespectively.

Forward ants are used to explore new paths in the network. Ants measure the current network state for instanceby trip times, hop-count, or Euclidean distance travelled. Backward ants serve the purpose of informing the originating node about the information collected by the forward ants.

The ACO-based algorithm provided better results in terms of throughput, delay jitter, etc. for environments of dynamic topology. It was discovered that in future, other ACO-based algorithms such as ARA, ABC, and AntHocNet would also be implemented on DSR protocol andthat Antnet algorithm would be implemented on other table-driven routing protocols.

2. Honey Bees Inspired Optimization Method: The Bees Algorithm

Optimization algorithms are search methods where the goal is to find an optimal solution to a problemin order to satisfy one or more objective functionspossibly subjected to a set of constraints. Studies of social animals and social insects have resulted in a number of computational models of swarm intelligence. Within these swarms, their collective behavior is usually very complex. The collective behavior of a swarm of social organisms emerges from the behaviors of the individuals of that swarm.

An optimization algorithm known asthe Bees Algorithm, inspired from the natural foraging behavior of honey bees to find the optimal solution was described by Yuce et al. (2013). The algorithm performs both an exploitative neighborhood search combined with random explorative search. After an explanation of the natural foraging behavior of honey bees, the basic Bees Algorithm and its improved versions were described and implemented in order to optimize several benchmark functions and the results were compared with those obtained with different optimization algorithms. The results showed that the Bees Algorithm could offer some advantages over other optimization methods according to the nature of the problem.

3. Route Recovery in MANETusing Particle Swarm Optimization (PSO)-based Node and Link Lifetime Prediction technique

There exist route failures in all conventional MANET systems' route discovery methodsresulting in data loss and communication overheads. Hence, routing has to be done in accordance with the mobility character of nodes in the network.To achieve this, Manickavelu and Vaidyanathan (2014) proposed a particle swarm optimization (PSO)-based lifetime prediction algorithm for route recovery in MANET. This technique predicted the lifetime of link and node in the available bandwidth based on the parameters such asrelative mobility of nodes, energy drain rate, etc. Using predictions, the parameters were fuzzified and fuzzy rules have been formed to decide on the node status. This information was made in order to be exchanged among all the nodes. Thus, the status of every node was verified before the data transmission processes started. Even for a weak node, the performance of a route recovery mechanism was made in such a way that the corresponding routes were diverted to the strong nodes. With the aid of the simulated results, the minimizations of data loss and communication overhead using PSO prediction were discussed in detail.

4. ACO (Ant Colony Optimization) as a Cluster Formation Technique

In MANETs, the mobility of nodes is one of the important factors to be taken into consideration; there has to be a certain way to determine the relative location of any node and thus, the cluster-based algorithm provides one of the best solutions to this problem. The fuzzy logic approach provides a method to find the degree of truthfulness and hence, can be best used to test the solution.

Arti et al. (2014) experimented on the same approach by proposing a cluster formation algorithmwhich provided a way to determine the node to be selected as a clusterhead within a cluster through the use of Ant Colony Optimization (ACO) technique. They designed the probability functionwhichaidedin determining the probability for various nodes to be selected as a cluster head.

With ABC (Ant colony Based Clusterhead) technique, cluster formation was achieved using the ACO (Ant Colony Optimization) mechanism so as to select the most stable path. A fuzzy logic system was then utilized to select the appropriate route by generating fuzzy rulesusing the followingparameters; B_ANT PKTs, mobility, and degree of nodes.

The cluster formation algorithm for disjoint clusters based on the Ant Colony Optimization technique promises to be one of the efficient ways of clustering algorithm and the results yielded by the fuzzy logic implementation with the MATLAB tool clearly showed that the probability of a given node to be selected as a cluster head is directly proportional to the number of backward Ant Packets received on a particular node. Finally, it was revealed that the proposed ABC selection algorithm could be used forever.

5. Routing Based on Ant-Like Mobile Agents

Ant-like mobile software agentswhich are analogous to those used in the Ant Colony Optimization (ACO) frameworkare employed for discovering network topologies, thus, achieving an efficient routing in the network. Ant-like mobile agents are effective means to discover the network topology in particular circumstances, for example, in MANETwhere the network topology frequently changes. Unlike a proactive routing algorithm, routing based on ant-like agents does not require frequent message exchanges for updating the routing tables. As the population of the network becomes dense, an ant-like agent becomes more effective in performing load-balancing operations in the network. Ant-like agents are the known means to mitigate congestion events in the network.

Ant-like mobile agents demonstrate their usefulness for solving some combinatorial optimization problems such asthe traveling salesman problem. The idea touse ant-like mobile agents in network control softwareso as to control the communication network was introduced in the late 1990s. Today, various control methods based on ant-like mobile agents have been proposed for telecommunication networks. The use of ant-like mobile agents for routing protocol was inspired by the fact that social insects like ants have remarkable abilities to solve complex problems in a distributed way.Individual insects act based on their local information; there is no central command yet overall coordination is accomplished. Ants communicate with each other through an indirect method called stigmergy. Each ant lays down a special chemical substance in its environment that is read by other ants to identify it as having been at a given location. This feature has often been reproduced in ant-like mobile agent algorithms. However, social insect society also has the ability to recover from individual members' erroneous behaviors or deaths.

Ant-like agents can successfully solve complex problems and self-organize, for example, if there are several routes from the nest of ants to a food source, the ants may find some of them, every time the ants transportfood from the source to the nest; they deposit pheromone so that the newly recruited ants can follow. When the ants deposit pheromone faster than its evaporation, the pheromone starts to accumulate. The more the ants follow a given path, the more the pheromone trail is strengthened. The ants may take the longest path as well as the shortest path. However, over time, the shortest route will accumulate greater pheromone density and it will attract more fellow ants. Such positive feedback works. Therefore, even though the ants find the shortest path later than longer ones, the shortest path eventually dominates. Deneubourg, Beckers, and other biologists, as well as computer scientists naturally, derive the engineering application from this observation (Kambayashi (2013)).

6. Routing in Data Networks Based on Mobile Agents

Routing is fundamental in communication network control. In data networks, it represents the action of addressing data traffic between pairs of source and destination nodes. In conjunction with flow control, congestion and admission, routing determines the total network performancein terms of quality and amount of servicesoffered. AntNet is an innovative algorithm for packet routing in communication networks in which, a group of mobile agents (or artificial ants) build paths between pairs of nodesexploring the network concurrently and exchanging the obtained information to update the routing tables. Therefore, this technique and its variants are promising alternatives for data routing in large-scale networks.

Barán and Sosa (2001) studied and studied two versions of AntNet algorithms, novel adaptive routing techniques for data networksbased on mobile agents, oriented towards packet switching such as the Internet. AntNet algorithms, in addition to RIP, OSPF, and LBR were implemented and simulated. A better performance of those versions of AntNet was observed in most of the experiments. The modifications implemented in the proposed versions that contributed the most for a better behavior were: a) Routing table's intelligent initializationb) Dual method for selecting jumping node for data packets.

The results of the experiments remained proportional. Results obtained in a different simulation scope suggest that AntNet algorithms could have better throughput as well as packet delay than RIP and OSPF. The authors then stated that if that was the case, it was expected that the modified algorithms proposed would have better performance than the original AntNet versions. An efficient AntNet behavior with flow control, congestion, and admission schemes were also expected. They finally said that it could be inferred that commercial implementation of this algorithm might be feasible and even considered for usage in large networks such as the Internet as a future option.

7. Swarm-based Intelligent Routing for MANETs

Prasad et al. (2009) conducted a study ona novel proactive algorithm to routingin mobile ad hoc networksknown as Probabilistic Ant Routingwhich was inspired by Ant Colony Optimization (ACO) framework and used “ants” for route discovery, maintenance, and improvement. The algorithm was based on a modification of the state transition rule of ACO routing algorithm that resulted in maintaining a higher degree of exploration along with congestion awareness in the search space. This led to reduced end-to-end delay and also lowered the overhead at high node density. The comparative experimental results of the proposed algorithm with the state-of-the-art AODV reactive routing algorithm of MANET were provided keeping mobility and density of nodes as main considerations. The proposed algorithm was tested for different network sizes and node mobilities. The experimental results were very promising as the proposed algorithm exhibited superior performance with respect to reactive AODV routing algorithm in terms of end-to-end delay.

8. Probabilistic Emergent Routing in MANET

As the highly dynamic topology, limited bandwidth availability, and energy constraints in MANET make the routing problem a challenging one, Baras et al. (2003) implemented the Probabilistic Emergent Routing Algorithm (PERA) for Mobile Ad hoc Networks; a novel approach to those routing problems inMANETsusing swarm intelligence-inspired algorithms. The proposed algorithm used Ant-like agents to discover and maintain paths in a MANET with dynamic topology. This algorithm exploited the inherent broadcast capability available in the wireless environment. With this approach, the process of route discovery was carried out by using a flooding mechanism to obtain and maintain paths between source-destination pairs in the network. Route discovery in this algorithm was done by two kinds of agents - forward and backward ants. Uniform ants were no longer required or feasible as the forward ants were broadcast rather than unicast. These agents created and adjusted a probability distribution at each node for the node’s neighbors. The agent packets or ants were of relatively small (variable) sizes. The probability associated with a neighbor reflected the relative likelihood of that neighbor forwarding and eventually delivering the packet. Further, multiple routes between the source and the destination were created. PERA was evaluated along with a set of routing algorithms for MANETs based on the swarm intelligence paradigm. It was observed that end-to-end delay for swarm based routing was low compared to AODV. However, the goodput for these algorithms was lower than for AODV in scenarios with high mobility.

9. Nature-inspired Scalable Routing in MANET

MANETs are multi-hop wireless networks consisting of radio-equipped nodes that are mobile. The topology of this type of wireless network changes frequently and this dynamicity makes it difficult to design an efficient routing protocol. A number of nodes in a MANET can be varied from a few nodes to hundreds and even more. Hence, it is important for a MANET routing protocol to keep its performance at an acceptable level withthe increasing number of nodes. A study that was motivated bynature to design a scalable routing protocol was providedby Gudakahriz et al. (2011). The proposed scheme NISR (Nature-Inspired Scalable Routing Protocol) improved the TORA routing protocol and borrowed some principles from both bee and ant colonies. With this protocol, an analogy between routing in MANETs and finding a source of food byant and bee colonies was presented. This new algorithm enhanced TORA by increasing the total delivered data, network,and system lifetime for a wide range number of nodes.

10. Hybrid Ant-based Routing

Mobile Ad hoc network is highly dynamic by nature and has limited bandwidth that makes the routing task very difficult. A number of Ant Colony optimization algorithms are used for routing in MANET. Different Ant-based MANET protocols are studied under various categories such asProactive protocol, Reactive protocols, and Hybrid protocols. Kaur et al. (2015) studied aboutthe same type of protocols; the Ant-AODV protocol was one among them which is a combinational algorithm of both ant-based routing mechanisms and AODV routing protocols to overcome their inbuilt drawbacks. This hybrid approach increased the node’s connectivity, decreased both the end-to-end delay and route discovery latency. Route establishment in conventional ant-based routing techniques is dependent on the ants visiting the node and providing the relevant routes. If a node needs to send data packets to a destination, it does not initially have any knowledge about the route to pass packets through, it will have to keep the data packets in its buffer till an ant arrives and provides the best route to that destination.

In Ant Routing Algorithms, there is no local connectivity maintenancewhich is not appropriate in real-time applications.On the other hand, AODV takes too much of time for connection establishment due to delay during the route discovery process.However,in Ant-based

Routing, a node having a route to the destination will immediately start sending data packets without any delay. Ant agents updated the routes unceasingly; a source node could switch from a longer route to a newer and shorter one provided by the ants. This resulted in a considerable decrease in the average end-to-end delay as compared to AODV routing scheme and Ant-Based Routing. They concluded that this algorithmwould be suitable for real-time data transmission and reduces route discovery latency.

11. Multi-agent Ant-based Routing in Mobile Ad hoc Networks

Single-path routing protocol known as Ad hoc On-demand Distance Vectorhas been widely studied for mobile ad hoc networks. AODV needs a new route discovery whenever a path breaks. Such frequent operations cause route discovery latency. To avoid such inefficiency, Kumar and Bhuvaneswaran (2007) experimented on a Multi-agent Ants based Routing Algorithm (MARA), a new algorithm for routing in mobile ad hoc networks. This hybrid protocol reduced route discovery latency and the end-to-end delay by providing high connectivity without requiring much of the scarce network capacity. The algorithm was based on the ideas from Ant Colony Optimization with Multi-agent systems technique. The simulation tests showed that MARA could outperform AODV, one of the most important current state-of-the-art algorithms. The research work ended with discussing the future improvement to the exploratory working of proactive ants.

12. Ant Routing Based on Adaptive Improvement

To efficiently perform multipath routing and offer an adaptive control mechanism, Yuan et al. (2005) conducted a study on an Ant Routing Algorithm for MANETs based on adaptive improvement; ARAAI, which combines both the advantages of proactive and reactive routing techniques. It isa self-configured, self-built, and distributed routing algorithm. ARAAI uses adaptive ant colony algorithm forthe mobile ad hoc routing process. Considering the slow astringency of ant colony algorithm, the adaptive ant colony routing algorithm was brought forward. It showeda great advantage for the mobility and dynamic topology network environment.It uses two routing tables, the first one can be represented by columns such as initial node, last node, and heuristic value. The initial node records the leaving initial place of ants. The last node records the address of the previous one and heuristic value is represented by the local node energy information. The second table contains the neighbor’s information and is represented as the connection between local and other relevant nodes. When a source node needs to transmit data packets, it first checks the routing table for any available route to the destination. If no route is found then the discovery process is immediately initiated. The comparative evaluation outcomes revealed that ARAAI was highly efficient and scalable comparing with existing AODV and DSR protocol.

13. Hybrid Routing Based on Ant Colony and ZHLS Routing Protocol for MANETs

As Mobile Ad hoc Networks (MANETs) require dynamic routing schemes for adequate performance, Kaur et al. (2015) examined a study on a prominent algorithm efficiently working in conjunction with the Zone-based Hierarchical Link State (ZHLS) routing protocol. ZHLS combines both proactive and reactive routing schemes; proactive is used within a zone and reactive operations are used in the area outside that zone or between different zones. The whole network is divided into nonoverlapping zones. Route discovery process is performed by Intrazone and Interzone routing mechanisms. The IntraRT basic structure is a matrix whose rows were its neighbors and the columns were all the identified nodes within its zone. During the route discovery process, for the Intrazone routing, each node periodically sends internal forward ants to its neighbors to maintain the Intrazone Routing table. This ant colony-based algorithm greatly reducedthe end-to-end delay and outperformed AODV in performance, this achievement was possible thanks to the zone framework i.e. the local intrusion routing table and Interzone routing table used in this QoS routing algorithm.

14. Orientation-based Ant Routing

Due to unpredictable network topological changes, routing in MANET is a challenging task and it requires a specialized approach to handling these changes due to the random movement of nodes. The routing protocol designed for MANETs should be able to detect and maintain route(s) between the source and the destination nodes in an efficient manner to handle the above-defined issues. In this direction, ant colony algorithm is an important category of meta-heuristics techniqueswhich can provide an efficient solution to many engineering problems. Nevertheless,most of the existing ant colony algorithms explore the search space without initial directionswhich leads to the risk of having local optima.

To address this issue, Singh et al. (2014) investigated an orientation based ant algorithm (OANTALG) for routing in MANETs in which the selection of destination nodes and the exchange of ants (agents) between the source and the destination is based upon the orientation factor. During the movement of ants, the pheromone tables and the data structureare created that recorded the ants' trip time between nodes through which ants make moves. An efficient algorithm for orientation based routing was also designed in the proposed scheme. The results obtained showed that the proposed algorithm performed better than the other state of art algorithmswhich are traditional and also other ant-based algorithms such as AODV, DSR, and HOPNET with respect to various performance metrics namelynumber of data packets sent, throughput, jitter, and path length.

15. Intelligent Multipath Routing for Mobile Ad hoc Networks

Conventional routing algorithms for Mobile Ad hoc networks such as AODV or DSR consider only one metric, for example, the hop-count to select the best path from source to destination. However, due to special characteristics of MANET such asnodal mobility, unstable links, limited resources, conventional routing algorithms have been found to be unsuitable for routing multimedia traffic or real-time applicationswhich require optimization of more than one metric. The paths chosen by conventional routing algorithms deviate far from optimal paths. Dharaskar and Goswami (2009) conducted an experimental evaluation of an algorithm called Fuzzy Stochastic Multipath Routing (FSMR) in which multiple metrics such as hop-count, battery power, and signal strength were considered using fuzzy logic to give multiple optimal paths. Nodes then forwarded data stochastically on these multiple paths resulting in automatic load balancing and fault tolerance. Finally, it was concluded that there were great improvements in FSMRover the conventional routing algorithm (for example AOMDV) in terms of various parameters such aspacket delivery ratio, the number of route discoveries, delay, etc.

16. Fuzzy Routing in Ad hoc Networks

Routing and related resource allocation issues present special challenges in ad hoc networks. Typically, every node in an ad hoc network serves as a router for other nodes, and paths from source to destination often require multiple hops. Compared to wired networks, wireless ad hoc networks have less bandwidth, longer paths, and less stable connectivity all of which render routing protocols from wired networks less suitable for the wireless world.

Gasim and Eric (2003) studied a novel routing scheme for ad hoc networks that applied fuzzy logic to differentiated resource allocation considering traffic importance and network state. Messages were routed over zero or more maximally disjoint paths to the destination, important packets might be forwarded redundantly over multiple disjoint paths for the increased reliability while less important traffic might be suppressed at the source. These protocols were built upon the route discovery mechanisms developed for existing MANET routing protocols such asDSR and SMR to identify as many disjoint paths from source to destination as possible. A fuzzy logic controller then determined, based upon the traffic importance and network status, how to use these paths for the offered traffic; split the traffic over the paths for load balancing, sent the traffic simultaneously over a plurality of the paths, or even rejected the traffic due to cost/benefit considerations. Simulation outcomes revealed that Fuzzy routingtriumphed in providing higher reliability and lower delay for important traffic than do the existing protocols, and in most cases offered better performance for all the traffics.

17. Genetic Fuzzy Multipath Routing andEvolutionary Computing

The inherent uncertainty in MANET due to nodal mobility, unstable links, and limited resources frequently render routing paths unusable. Thus, recurrent route discoveries detrimentally affect the network performance. The most promising solution is to use multiple redundant paths for routing. However, selecting an optimal path set is anNP-hard problem. Most current multipath routing protocols do not concentrate on the uncertainty in MANET. They choose an "optimal" multipath set by considering only one single route selection parameter such as the least number of intermediate hops or the maximal remaining battery power. As a result, they miss the correlations among the multiple route selection parameters.

Liu et al. (2005) experimented on an efficient algorithm; Genetic Fuzzy Multipath Routing Protocol (GFMRP)which combines the fuzzy and evolutionary features. This multi-path routing protocol naturally deals with the uncertainty in MANET and adaptively construct a set of highly reliable paths by considering the interplays among multiple route selection parameters. GFMRP takes into account four important factors as the selection parameters namelythe energy consumption rate, queue occupancy rate, link stability, and the number of intermediate nodes.

The performance of GFMRP revealed that it can bewell suited to the ad hoc environment as itoutperformed DSR, SMR, and SBMR.

2.1.3 Multicasting and Broadcasting Techniquesin MANET

Broadcast and multicast are important operations for mobile hosts to construct a routing path in MANET. The broadcast is a communication function in which a node referred to asthe sourcesends messages to all the other nodes in the network. Broadcasting is an important function for applications of ad hoc networks in cooperative operations, group discussions, and route discovery. Broadcast routing usually consists of constructing a broadcast treewhich is rooted from the source and contains all nodes available in the network. In addition to broadcasting, multicasting is another important function in applications including distributed games, replicated file systems, and teleconferencing. Multicast in a MANET is defined by delivering multicast packets from a single source node to all other member nodes in a multi-hop communication manner. Various researchers have investigated those type of protocols, for example, Patturose andVinoth (2013) have reviewed various MANET routing protocols; Multicast Ad hoc On-Demand Distance Vector (MAODV) protocol, Improved Multicast Ad hoc On-Demand Distance Vector (IMAODV) protocol, On-demand Multicast Routing Protocol (ODMRP), and Adaptive Demand-Driven Multicast Routing (ADMR) routing protocols.

Jain andAgrawal (2014) also conducted a general survey on multicast routing protocols available in MANETs. Theyclassified those protocols into three main categories: mesh-based, tree-based, and hybrid-based protocols. The outcomes from their research revealed that mesh-based protocols are efficient in dealing with the dynamicity of topology and are more stable while tree-based protocols are robust for highly successful data transmission operations. They finally stated that those protocols have their own strengths and weaknesses; hybrid multicast provides the best features of both tree-based and mesh-based Protocols.

More previousstudies on both types of protocols are provided in the next section:

18. On-demand QoS and Stability-based Multicast Routing in Mobile Ad hoc Networks

To provide high QoS in real-time applications inMANETs,Basarkod and Manvi (2014) designed an extension of the Ad hoc On-Demand Multicast Routing Protocol (ODMRP), the new enhancement for this protocol was called “an On-demand Quality of Service (QoS) and stability-based Multicast Routing (OQSMR) scheme”. The new algorithm was implemented as follows: first of all, each participating node in the network periodically calculates various network parameters i.e. link and node stability, bandwidth ratio, and delay at each node. It also performs the link and route maintenance operations in the events of route failures. This drastically reduced both the overhead and end-to-end delays incurred in the network, thus, increasing the Packet Delivery Ratio. The authors stated that in future, theresearchcan be extended by comparing OQSMR protocol with some other QoS-based routing protocols in MANETs.

19. A Taxonomy of Multicast Routing Protocols and Approaches for QoS Provision in MANET

Sutariya and Kamboj (2013) studied various QoS multicast routing protocols for Mobile Ad hoc Networks. Ataxonomy of multicast routing protocols and approaches for QoS provision in MANET were defined. Several QoS multicast routing protocols were studied and defined in terms of summary attributes and performance evaluation parameters. They said that based on the survey, several common themes emerged regarding limitation of the existing QoS multicast routing in MANETs. All the approaches focused on bandwidth as QoS constraint while few focused on delay, jitter, and other parameters. In few of the algorithms, service classification was considered which is important for various multimedia applications. A similarity did not exist in the performance evaluation of the protocols. The parameters varied to a larger degree. Scalability issue was not considered by most of the approaches. Performance evaluation with respect to different parameters and heterogeneity issues were focused tolimited extents. According to their previous discussion, they proposed that in future QoS multicast routing algorithm for multimedia applications be focused on solving the above issues.

20. A QoS-aware Multicast Routing Scheme for MANET

Huang and Liu (2010) attempted a study on a QoS-Aware Multicast Routing algorithm for MANET; multi-objective evolutionary algorithm (MOEAQ) which mainly aimed at solving the multicast routing protocol-related problems. The limitation and strengths of the "well-known multicast model" with the ''Greedy" and ''family competition"; approaches integrated into this algorithm were successful in speeding up the convergence and maintaining the diversity of the population. They then proposed a Core Based Tree-based protocol to simplify MRP (Multicast Routing Problem); the network was scaled from 20 to 200 nodes with different types of service and evaluated using the OPNET simulator, the simulation outcomes revealed that the proposed scheme was able to achieve faster convergence for multicast routing in MANET compared to other Genetic Algorithm-based protocols existing in the literature.

21. Tree-based Multicast Routing in MANET

Tree-based protocols construct a tree through which multicast data is promoted which happens only in fixed (non-mobile) multicast routing. Though tree-based strategies are bandwidth-competent they have few drawbacks such asmobility prone to link failure and they do not provide adequate robustness.

Bommaiah et al. (1998)investigated a tree-based multicast routing protocol for Mobile Ad hoc Networks, AMRoute (Adhoc Multicast Routing Protocol). This protocol has two key phases namelymesh creation and tree creation. This protocol isused for networks in which only a set of nodes supportAMRoute routing function. Using AM Route, bi-directional unicast tunnels are continuously created between pairs of group members that are close together. In contrast to the multicast group members, some nodes for tunnel construction don't support AMRoute. When one sends a packet to a logically adjacent member, the packet will be physically sent on a unicast tunnel and may pass through many routes. The unicast tunnels form a mesh for each multicast group. AMRoute constructs a multicast distribution tree periodically for each multicast group based on the mesh links available. AMROUTE has been proven to be effective in increasing the network performance as its signaling traffic remains at a relatively lowlevel for typical group sizes and group members receive a high proportion of data multicast by senderseven in the case of a highly dynamic network.

22. Improving the Performance of Probabilistic Flooding in MANETs

Broadcasting in Mobile Ad hoc Networks has traditionally been based on flooding which swamps the network with a large number of rebroadcast packets in order to reach all the network nodes. The appropriate use of probabilistic broadcasting can reduce the number of packet transmission, effectively alleviating the problem of contention. In particular, a good probabilistic broadcast protocol can achieve both higher saved rebroadcast and higher reachability.

Considering nodes distribution and movement issues, Yassein et al. (2005) made a study on a new probabilistic mechanismwhich dynamically adjusts the rebroadcasting probability. This technique was successful without requiring any help of distance measurements or any location determining device such asGPS, only locally available information was used for this end. Simple flooding and fixed probabilistic approaches were evaluated against this proposed mechanism;the performance of the proposed approach was evaluated by comparing it with simple flooding as well as a fixed probabilistic approach.The outcome showed that the new algorithm exhibited better performance in terms of both the saved rebroadcasts and reachability parameters.

23. Optimized Multicast Routing Approach Based on Tree Structure in MANETs

Since nodes in MANET move randomly, routing protocols must be highly effective and reliable to guarantee successful packet delivery. Based on the data delivery structure, most of the existing multicast routing protocols can be classified into two categories: tree-based and mesh-based. Tree-based multicast routing protocols have high forwarding efficiency and low consumptions of bandwidth, and they may have poor robustness because only one link exists between two nodes.MAODV (Multicast Ad hoc On-demand Vector) is one of the tree-based multicast routing protocols which shows an excellent performance in lightweight ad hoc networks. It is disadvantageous in heavy-weighted MANETs when the load of the network increases as QoS (Quality of Service) is degraded obviously.

Xu et al. (2014) made an attempt to find an extension to theMAODV protocol; MAODV-BB. This enhanced protocol combines the advantages of both tree and mesh structures. The main feature of this algorithm is the full use of GRPH messages that the group leader periodically broadcasts to update shorter tree branches and construct a multicast tree with backup branches resulting in an optimized tree structure and reduced frequency of tree reconstruction. Both mathematical and simulation models proved that MAODV-BB highly increased the network performance when compared to MAODV in heavy load ad hoc networks. In future, the authors would focus on the reliability of the tree-based multicast routing protocol varying the mobility frequency and group size. They also intend to solve the problem of fast data transmission rate tothe sender by slowing it down when the network is highly loadedthanks to the congestion control mechanism.

24. Ad hoc Multicast Routing Protocol Utilizing Increasing ID numbers

Gupta and Saxena (2015) presented AMRIS (Ad hoc Multicast Routing protocol utilizing increasing id-numbers), a multicast protocol designed to operate independently of the underlying unicast protocols. The idea behind AMRIS is to dynamically assign every node (on demand) in a multicast session with an id-number. The ordering between id-numbers is used to direct the multicast flow and the sparseness among them is used for quick connectivity repair. A multicast delivery tree rooted at a special node known as Sid joinsthe nodes participating in the multicast session. The relationship between the id-numbers (and the nodes that owned them) and Sid is that the id-numbers increase in numerical values as they radiate from Sid in the delivery tree. These id-numbers help the nodes dynamically leave and join a sessionas well as adapt rapidly to changes in link connectivity (due to mobility, etc). Messages to repair a link breakage are confined to the region where it occurred**.** It was reported that AMRIS presents both advantages and disadvantages.

Advantages:

1. The concept of increasing id-numbers is useful for constructing and maintaining a multicast tree.
2. It may incur very low overhead for a node to join or rejoin the session if it chooses a potential parent nodewhich happens to be a tree node.

Disadvantages:

1. Joining and rejoining of a node may take a long time and waste much bandwidth since each node tries potential parent nodes arbitrarily.
2. The usage of periodic beacons consumes bandwidth.

2.1.4 Genetic Algorithms

Genetic Algorithm (GA) is a probabilistic search algorithm based on the mechanism of selection and genetics. This algorithm is started with a set of solutions (represented by chromosomes) called population. Solutions from one population are taken and used to form a new population. This is motivated by a hope that the new population will be better than the old one. Solutionswhich are selected to form new solutions (offspring) are selected according to their fitness - the more suitable they are, the more chances they have to reproduce. In other words, for each generation, the population size is preserved and at each generation, each chromosome fitness value is evaluated. A chromosome for the next generation is selected based on the fitness probability value. Selected chromosome must have a high probability value than the previous generation. This process is continued until the end of the requirement gets satisfied (Jain and Sahu (2012)).

Various researches have been carried out on genetic algorithms, some are provided in the following section:

25. Multicast Routing with Bandwidth and Delay Constraints Based on Genetic Algorithm

Many multimedia communication applications require a source to send multimedia information to multiple destinations through a communication network. To support these applications, it is necessary to determine a multicast tree of minimal cost to connect the source node to the destination nodes subject to delay constraints on multimedia communication. This problem is known as multimedia multicast routing and has been proven to be NP-complete. Singh andYadav (2015)found out agenetic algorithm for solving multimedia multicast routingwhich identifiesthe low-cost multicasting tree with bandwidth and delay constraints. In that algorithm, the k shortest paths from the source node to the destination nodes were used for genotype representation. It uses the k^{th} shortest path algorithms to construct route set. The encoding space can be improved by finding out all the routes that satisfy bandwidth constraint from the source node to the destination node and composing routes set as candidate routes set of genetic algorithms encoding space.

The algorithm guaranteed and speeded up the searching ability of the optimal solution and the global convergence of solution by heuristic crossover and mutation operation could be achieved. It has been shown that it can affectthe multicast routing of large computer networks. It was also stated that the algorithm can be applied to multiconstraint QoS multicast routing problem; only the chromosome will be changed and the delay constraintbe improved so as to make the algorithm widely applied.

26. Multiple Constraints QoS Multicast Routing Optimization Based onGenetic Algorithm in MANET

As multiple Quality of Service (QoS) guarantees are required in most multicast applications, Sun et al. (2008) conducted a research study on multiple constraints algorithm for multicast traffic engineering in MANET. The algorithm was a new version of multiple constraints QoS multicast routing optimization algorithm in MANET based on genetic algorithm (MQMGA). MQMGA can optimize the maximum link utilization, the cost of the multicast tree, the selection of the long-life path, the average delay, and the maximum end-to-end delay. The experiments revealed that the schemehad promising performance in multicast traffic engineering and was efficient in evaluating the route stability in dynamic mobile networks.The authors finally stated that although the proposed GA provided a conservative tool to solve multicast routing problems with diverse QoS constraints in MANET, further elaboration on generalizing the idea isrequired.

27. QoS Multicasting Routing Based on Immune Genetic Method in NGN

NGN (Next Generation Network) is a packet-based networkwhich can provide services including Telecommunication Services and is able to make use of multiple broadbands, Quality of Service-enabled transport technologies in which service-related functions are independent of underlying transport-related technologies.NGN is a type of networkwhich is different from the existing types of networks. Lin et al. (2010) introduced an algorithmwhich was based on NGN technology known as “Improved Immune Genetic Routing Algorithm” [KIGAE]which considers multiple constraints such as delay, delay jitter, bandwidth, and packet loss.

Even though there are somedrawbacks of GA such as incomplete convergence and weak local searchability, the algorithm is based on the improved immune genetic algorithm in NGN. It is able to improve the method of establishing alternative path set using K-path label algorithm (KPLA), it improves the genetic operator crossover, mutation, and introduces the mechanism ofthe judgment of local optimum while also satisfying the demand of QoS multicast in NGN. The algorithm canalso provide global convergence and jump from local optimum.

28. Multicast Routing with Delay and Delay Variation Constraints using Genetic Algorithm

Delay is an important, critical, and more sensitive factor in various real-time applications. Hamdan andHawary (2004) conducted a study on a constrained multicast routing scheme based on genetic algorithm, GADVM (Multicasting routing with Delay and Delay variation constraints using Genetic Algorithm). The algorithm considered constraints which represented the Quality of Service (QoS) measures that a network should provide for real-time applications. First, a constraint on end-to-end delay from source to each destinationandsecond, bounded delay variations along the paths from source to each destination werecompared with four known multicast routing algorithms namely BSMA (Bounded Shortest Multicast Algorithm), CDKS (constrained Dijkstra heuristic), SPT (Shortest Path Tree). Two performance metrics were considered, the failure rate and average cost per path. It was demonstrated that the GADVM algorithmperformed favorably and displayedmuch lower failure rates; its cost was also comparable withand in some cases better thanthe other algorithms. GADVM performed well in terms of average cost and failure rate per path.

29. Energy Efficient Multicast Routing using Genetic Algorithm in MANET

In ad hoc networks, mobile node battery energy is finite and represents one of the greatest constraints for designing multicast routing protocols. With respectto the battery lifetime limitation in supporting multicast routing, some studies have investigated a power saving network layer. These proposed methods have always considered several techniques such asroute load for relaying, battery lifetime in route selection, decreasing the frequency of sending control messages, optimizing the size of control headers, and efficient route reconfiguration techniques.

A research workthat discusses the multicast routing problem with multiple QoS constraints in MANETs was presented by Yen et al. (2008). It is also an *NP-Complete* problem that deals with various constraintsandimplements an energy-efficient genetic algorithm to resolve those problems. A source-tree-based routing algorithm was designed and the shortest-path multicast tree built to minimize delay time by using a small population size in the genetic algorithm. Only a few nodes were involved in route computation. An improvement was provided bothto the genetic sequence and topology encoding, thus, prolonging the lifetime of mobile nodes that calculate the residual battery energy of all nodes in a multicast tree.

30. Efficient Multi-objective QoS Routing for Wireless Multicasting

Determination of QoS-based optimal multicast routes boils down to a multi-objective optimization problemwhich is computationally intractable in polynomial time. As a result, to optimize the multicast routes that strictly satisfy the QoS constraints, Roy et al. (2002) investigated a multicast tree selection algorithm based on the non-dominated sorting technique of the genetic algorithm, NS-GA (Non-dominated Sorting Genetic Algorithm). Parameter metrics considered in this algorithm are bandwidth, end-to-end delay, bandwidth utilization,and provisioning. The algorithm uses ranking techniques in which rank population is performed by the use of non-domination of strings. It is capable of discovering a set of QoS-based near optimal, non-dominated multicast routes within a few iterations. From thatset, the user can choose desirably favorite solution depending on specific QoS requirements. The protocol was scalable and preferredforincreasing the number of network nodes.

31. QoS Parameter Optimization using Multi-objective Genetic Algorithm

The increase in the proliferation of mobile devices and wireless technologies in recent years has opened up new challenges for MANET. This growth has also led to an increase in demand for applications such asstreaming video, multi-player interactive games, and financial services such asreal-time stock quotes. Such applications impose a strict guarantee on Quality of Service (QoS) namely end-to-end delay, bandwidth consumption, and cost. Nevertheless, finding a path that satisfies multiple constraints is inherently hard. Furthermore, challenges occur with routing in a mobile environment where nodes are mobile; the data delivery path constantly changes and routing is constrained by battery levels. Multicast routing can improve network usage by sharing resources when sending messages to multiple destinations especiallywhen multiple mobile nodes are located within the transmission range of a node.

MOGA (MultiObjective Genetic Algorithm Based Adaptive QoS Routing in MANET) is an algorithm recognized to be well qualified to tackle multi-objective optimization problems. The process starts by finding all non-dominated chromosomes of a population and assigns themthe rank of one. These chromosomes are removed from the population. Next, all the non-dominated chromosomes of this smaller population are found and assigned the rank of two. This process continues until all chromosomes are assigned a rank. The largest rank will be less than or equal to the size of the population. Usually, there are many solutions that have the same rank. The selection procedure uses the chromosome ranking to determine the mating pool. MOGA also uses niching on the cost to distribute the population over the Pareto optimal region. The findings proved MOGA to be robust and scales well for a relatively large number of nodes (Asraf et al. (2010)).

32. QoS Multicast Routing using Evolutionary Algorithm

Multicast routing is regarded as a critical component in networks,especiallyin the real-time applicationswhich havebecome increasingly popular in recent years. Existing multicast routing under certain QoS constraints tends to use conventional IP QoS architecture based on GA.

QMOEA (QoS multicast routing evolutionary algorithm) also termed “Novel and fast multi-objective evolutionary algorithm for QoS Multicasting routing in MANETs”studied by Liu andHuang (2009) is a novel fast multi-objective evolutionary algorithm efficient in solving multicast routing problem (MRP) in MANET. Through the analysis of the strengths and limitations of the well-known multicast architecture, an improved Core Based Tree model to simplify the MRP was first given. Based on this model, QMOEA was then usedwhich integrated the “Greedy” and “family competition” approaches to speed up the convergence and maintain the diversity of the population. Experiments confirmed that QMOEA was capable of achieving faster convergence and more preferable for multicast routing in MANET compared to other Genetic Algorithms well-known in the literature.

33. Multi-objective Model for QoS Multicast Routing based on Genetic Algorithm

Usually, multiple Quality of Service (QoS) guarantees are required in most of the multicast applications. An efficient allocation of network resources to satisfy the different QoS requirements is the primary goal of QoS-based multicast routing. However, the inter-dependency and confliction among multiple QoS parameters make the problem difficult. It has been demonstrated that it is NP-complete to find a feasible multicast tree with two independent additive path constraints.Cuiet al. (2003) studied an approach, the multiobjective model for QoS Multicast Routing based on genetic algorithmalso formulated as a multi-objective constrained combinatorial optimization problem for a protocol to determine multicast routes satisfying different QoS requirements. A multi-objective model and routing approach based on the genetic algorithm that optimized multiple QoS parameters simultaneously wasused. The approach was capable of discovering a set of non-dominated routes within a finite evolutionary generation. Its feasibility and performance have been peer-verified in the literature.

34. Tree-based Genetic Algorithm with Binary Encoding for QoS Routing

Mobile Ad hoc Networks (MANETs) are one of the most important technologies supporting Ubiquitous and Pervasive Computing (UPC). As many UPC applications pose Quality of Service (QoS) constraints, their implementation in MANETs becomes dependent on the MANET algorithms for QoS routing. A study which considers Genetic Algorithms (GAs) for QoS routing in MANETs was evaluated by Maniscalco et al. (2013). GAs can solve the NP search of QoS routes with multiple constraintsand then address the UPC QoS requirements. The focus was on tree-based Gaswhich representthe set of paths from source to destination as a tree and encodes them through the crossed junctions. They encode single paths in the chromosome. The authors investigated the effects of binary encoding schema on tree-based GAs. For this purpose, they designed a GA with binary encoding that maps classes of paths in single chromosomes. These classes are both collectively exhaustive and mutually exclusive. The GA with binary encoding uses an adaptive mutation probability for deeper exploration of the search space and local search on classes of paths. Simulation results compared GA with binary encoding using two applications of GAMAN, the main existing tree-based GA. They showed that the binary encoding allowedGA to converge faster although it introduced additional computational costs.

2.1.5 Packet Scheduling Techniques

A network scheduler, alsodenoted as packet scheduleris an arbiter program on a node in the packet switching communication network. It manages the sequence of network packets in the transit and receives queues of the network interface controller which are circular data. In the course of time, several network scheduling algorithms (also called queuing discipline, qdisc or queuing algorithm) have been developed. Each of the scheduling algorithms used internally for these queuing disciplines provides specific reordering or dropping of network packets inside various transmit or receive buffers.Queuing disciplines are commonly used as attempts to compensate for various networking conditionsviz.reducing the latency for certain classes of network packets and are generally used as part of the quality of service (QoS) measures.

The choice of the scheduling algorithm to determine thequeued packet tobe processed next will have a significant effect on the overall end-to-end performance when the traffic load is high. For this, various scheduling algorithms were studied. Most current researches on MANET use a simple priority scheduling algorithm for the simulationwhere data packets are scheduled in FIFO order and all routing packets (RREQ, RREP, and RERR) are given priority over data packets for transmission at the network interface queue. There are several scheduling policies for different network scenarios. Different routing protocols use different methods of scheduling. The drop-tail policy is used as a queue management algorithm in all scheduling algorithms for buffer management.

For the scheduling algorithms that give high priority to control packets, different drop policies are used for data and control packets when the buffer is full. Except for the no-priority scheduling algorithm, all the other ones give higher priorities to control packets than to data packets. The differences in the algorithms are in assigning priorities between data packets. Currently, only priority scheduling is used in mobile ad hoc networks. Different scheduling algorithms are devised by using distance metrics, considering fairness, and applying the multiple roles of nodes as both routers and data sources.

The scheduling algorithms that give higher weights to data packets with a smaller number of hops or shorter geographic distances to their destinations reduce the average delay significantly and improve the average throughput. Network traffic can be classified into two categoriesascontrol packets and data packets. Scheduling can be classified intopacket scheduling and channel access scheduling. Packet scheduling decidesthe order in which packets waiting for transmission at any node must be dispatched and thechannel access scheduling decides how different nodes share a channel in thecontention region (Garg and Singh (2012)).

35. Efficient Priority Packet Scheduling

Scheduling real-time and non-real-time packets at the sensor nodes is significantly important to reduce processing overhead, energy consumption, communicationbandwidth, and end-to-end data transmission delay in Wireless Sensor Network (WSN). Most of the existing packet scheduling algorithms of WSN use assignments based on First-Come-First-Served

(FCFS), non-preemptive priority, and preemptive priority scheduling. However, these algorithms incur a large processing overhead and data transmission delay and are not dynamic to the data traffic changes.

Lutful Karim et al. (2012) introduceda three-class priority packet scheduling scheme. Emergent real-time packets were placed into the highest priority queue and could preempt the processing of packets at other queues. Other packets were prioritized based on the location of sensor nodes and were placed into two other queues. Lowest priority packets could preempt the processing of their immediate higher priority packets after waiting for a certain number of timeslots. The experimental results revealed that the three-class priority packet scheduling scheme outperformed FCFS and multilevel queue schedulers in terms of end-to-end data transmission delay.

36. Delay-sensitive Packet Scheduling in MANET by Cross-layer

E.Vaidhegi et al. (2014) experimented on the delay-sensitive packet scheduling and routing algorithm to effectively deliver delay-sensitive data over multi-hop networks. First, the packet urgency, node urgency, and route urgency were calculated on the basis of end-to-end delay requirements. The scheduling algorithm at theMAC layer and routing algorithm atthe network layer were tightly coupled on the basis of urgency metrics. Based on these urgency metrics, the proposed packet scheduling algorithm determinedthe transmission order of each packet to minimize the node urgency without unnecessary packet drop.Italso established a route to minimize the derivatives of route urgency in order to maximize the number of packets delivered within the required end-to-end delay.

37. Packet Prioritization in Multi-hop Latency-aware Scheduling for Delay Constrained Communication

To address the problem of optimization of packet transmission schedule in multi-hop wireless networkswith end-to-end delay constraints, Ben Liang and Min Dong (2007) conducted a study on a scheduling algorithm. The emphasis was to determine the proper relative weights assigned to the remaining distance and the remaining lifetime in order to rank the urgency of a packet. They considered a general class of cross-layer transmission schemes that represented such relative weights using a single lifetime-distance factor which includedspecial casesandschedules such as earliest-deadline-first and largest-distance-first. An analytical frameworkbased on recursive non-homogeneous Markovian analysis was proposed to study the effect of the lifetime-distance factor on packet loss probability in a general multi-hop environment with different configurations of peer node channel contention. Numerical results were presented to illustrate how various network parameters affect the optimal lifetime-distance factor. The authors demonstrated quantitatively how the proper balance between distance and lifetime in a transmission schedule can significantly improve the network performanceeven under imperfect schedule implementation.

38. A QoS-Oriented Distributed Routing Approachin Hybrid Wireless Networks

This mechanism studied by Ze Li and Haiying Shen (2014) is efficient in achieving a high Quality of Service (QoS) for highly dynamic hybrid networks. The protocol incorporates five different algorithms in order to improve the transmission QoS. Those algorithms are:

1. QoS guaranteed neighbor selection algorithm for meeting the transmission delay requirement to reduce the packet transmission delay ratio. The algorithm is based on deadline driven scheduling algorithm for data traffic scheduling in intermediate nodes. An intermediate node assigns the highest priority to the closest deadline packet and thensends this packet first.
2. A distributed packet scheduling algorithm is required for reducing the transmission time. The algorithm assigns earlier generated packets to forwarders with higher queuing delays and scheduling feasibilities. It assigns a more recently created packet to forwarders with lower queuing delays and scheduling feasibilities so that the transmission delay of a whole packet stream got decreased.
3. A mobility-based segment resizing algorithm that flexibly accommodates the segment size in accordance to node mobility in order to reduce transmission time. The large-sized packets are assigned to lower mobility nodes and intermediate nodes and small-sized packets are assigned to intermediate nodes with higher mobilities. It efficiently increases the QoS-guaranteed packet transmissions.
4. A traffic redundant elimination algorithm to increase the transmission throughput. Itis a soft deadline-based forwarding scheduling algorithm. In order to achieve fairness in the packet forwarding scheduling in soft driven applications, a forwarding node can use the least slack first scheduling algorithm.

5. A data redundancy elimination-based transmission algorithm to eliminate the redundant data to further improve the transmission QoS. Data redundancy can be eliminated by introducing the NAV values based on the overhearing message transmission durations. When NAV value gets reduced, the scheduling feasibilities of the intermediate nodescan be increased and automatically, the QoS of the packet transmission will increase. To overcome the problem of both mobile nodes' routing overhead and cache packets' overhead, the authors proposed the end-to-end traffic redundancy elimination (TRE) algorithm to eliminate the redundant data and to improve the QoS of the packet transmission.

The simulation results of their experiments conducted by applying the evaluating parameter metrics namelythe overhead, transmission delay, mobility-resilience, and scalability revealed that QOD outperformed for all the studied cases.

39. Providing Fairness to Applications with Different Priorities using Dynamic Priority Packet Scheduler withDeadline Consideration

Providing Quality of Service (QoS) to applications with different traffic characteristics based on their needs is an important research area for today's and tomorrow's high-speed networks. Various techniques have been proposed to achieve good QoS for diverse application types. Among these techniques, packet scheduling algorithms decide to how to process packets at network nodes.However, they have limited support for better QoS. In order to offerthe various QoS requirements for different kinds of applications, new scheduling policies need to be developed and evaluated.

Tamer DAG (2006) made an attempt to finda new kind of packet scheduling algorithm, Dynamic Priority with Deadline Considerations (DPD)which integrates an important QoS parameter (the delay) into the classical static priority packet scheduling algorithm and analyses the packet losses by considering two different components of losses; buffer overflows and deadline violations. The proposed algorithm not only reduces the complexity of the static priority algorithm by introducing degree sorting but also solves the starving problem and provides fairness to applications with different priorities.

40. A Study of MANET Performance under Limited Buffer and Packet Lifetime

Generally, the global network lifetime can be affected by various factors such as nodes and lifetime oflinkswhich can fail due to limited nodebattery power or other constraints. Yujian Fang et al. (2015) examined the study onthe other two important constraints which could be used to determine the overall lifetime of MANET namely buffer size and packet lifetime.Theimpacts of the two constraints on the global network lifetime were explored. Thestudy used the embedded Markov chain theory to develop a complete theoretical framework and the packet end-to-end delay was studied based on M/G/1/K queuing theory.The packet end-to-end delay under any exogenous rate was further studied to give a relatively whole picture of how buffer size and packet lifetimewould impact the network throughput, packet loss ratio, and packet delay.

2.1.6 Network Lifetime Prediction Routing and Energy Conservation

One of the main design constraints in mobile MANETs is that they are power-constrained. Hence, every effort is to be channeled towards reducing power consumed by nodes. More precisely, network lifetime is a key design metric in MANETs. Since every node has to perform the functions of a router, if some nodes die early due to lack of energy, it will not be possible for the other nodes to communicate with each other. Consequently, the network will get disconnected and the network lifetime will be adversely affected (Morteza Maleki et al., 2003).

41. Maximizing the Network Lifetime of MANET using Efficient Power and Life -aware Routing Scheme

The mobile devices in MANET are battery driven and the communication may tend to break up due to the energy exhaustion of nodes. Hence, it is very important to extend the battery lifetime of mobile devices. Generally, MANETs establish communication among different mobile nodes, the death of even few of the nodes due to power exhaustion might cause the disconnection of services in the entire network. Anuja et al. (2014) conducted a study on a new on-demand source routing protocol, the Efficient Power and Life-Aware Routing Protocol (EPLAR) to increase the network lifetime of MANET. The position of nodes and the time at which nodes stayed stable in a particular position were determined. The battery power of each node was calculated and thus, the path with the lowest hop energy allocated to each linkwas determined. The energy consumed by nodes increased when a path failed due to frequent movement of nodes. Hence, alternate paths from the source node to destination nodes were identified and the packets were transmitted.

42. Future Battery Lifetime Prediction with Efficient Power-aware Routing

As the mobile nodesin MANET are battery-powered and constrained by the limited lifetime of battery power; this issue makes a node's active state short due to unrealistic shutdown or restart. Increasing each node battery's lifetime is a challenging task in MANET; this is accomplished by designing and implementing a power-aware routing protocolwhich takes power optimization approaches into account; a technique being rarely implemented with native routing protocols. EPAR is a new on-demand, power-aware routing protocol with the ability to predict future battery lifetime. It does so to reduce the total energy consumed by packets traversing fromsource to destination by identifying the node capacity using its remaining battery power whilealso considering the energy used to forward packets over various links. The path is chosen based on energy and the selection is done by computing the lowest hop energy allocated to each link. By doing so, it reduces the overall energy consumed, thus, decreasing the end-to-end delay and increasing the end-to-end packet delivery ratio. It is advantageous forlarge, highly dynamic networks as it prolongs the network lifetime (Marcel and Vetrivelan, 2015).

43. Reliable Link-based Routing in Highly Dynamic Mobile Ad hoc Networks

Sahaya Rose Vigita et al. (2013) designed a new Link and Position-based Opportunistic Routing protocol (L-POR), a stateless geographic routing protocol ensuring reliable data delivery. The protocol selects a forwarder node based on its reception powerwhich has overcome the problem related to link instability; a major factor causing unreliable data delivery. They also proposeda backup scheme aiming at handling communicationholes. The experimental outcomes revealed that the protocol improvedthe routing performance for highly dynamic networks with high node mobility. As the distance from the node towards the destination had not been considered for forwarder selection criterion in theirstudy, the path length might not always be minimalcausing a varying end-to-end delay. Hence, it was proposed that a future research on the same protocol should be done to reduce the hop-count for ensuring a lower end-to-end delay.

44. Improving the Network Lifetime of MANETs through Cooperative MAC Protocol Design

The notion of cooperation takes full advantage of the broadcast nature of the wireless channel and creates spatial diversity, thereby, achieving tremendous improvement in system robustness, capacity, delay, and provides a significant reduction in interference and extension of coverage range. Xiaoyan Wang and Jie Li (2015) followed the same approach and proposed a new cross-layer distributed energy-adaptive location-based CMAC protocol whichwasdenoted as DEL-CMAC for MANETs. The main objective of this protocol was to improve the performance of MANET based on network lifetime and energy efficiency. An innovative network allocation vector setting was provided for dealing with the varying transmitting power of the source and relaying terminals. The energy consumption was based on both transceiver circuitry and transmit amplifier. A distributed utility-based relay selection strategy was incorporated and the best relay was selected based on both locationinformation and residual energy. Furthermore, with the purpose of enhancing the spatial reuse, an innovative network allocation vector setting was provided to deal with the varying transmitting power of the source and relay terminals. DEL-CMAC significantly prolonged the network lifetime under various circumstances even for high circuitry energy consumption cases ina comprehensive simulation study.

45. Maximizing Multicast Communication Lifetime in Wireless Mobile Ad hoc Networks

Song Guo and Oliver Yang (2008) investigated the problems of maximizing the lifetime of MANETs with routing features such asmulticast connection, omnidirectional antenna usage, and having fewer energy resources. They proposed two distributed multicast algorithms namelyBasic Energy-Efficient Multicast (BEEM) and Distributed Maximum Lifetime Multicast (DMLM) tomaximize the network lifetimewhere nodes freely and randomly move in the network. Those algorithms explored various operations in the network taking advantage of the power saving options offered by the wireless multicast property in mobile networks. Through simulation studies, DMLM algorithm outperformed in all the cases studied by changing the speeds of node mobility.

46. Forecasting the Node Lifetime through Energy Drain Rate

Untethered nodes in mobile adhoc networks strongly depend on the efficient usages of their batteries. The current condition of the network can worsen due to inefficient power management. In this context, whileconsidering current traffic conditions in the network, Dongkyun Kim et al. (2003) made a study on a metric called ‘the drain rate’ aiming at forecasting the lifetimes of nodes. Combined with the remaining battery’s power values, nodes were selected to be parts of an active route.They defined two route selection approaches in MANET namelyMinimum Drain Rate (MDR). MDR extended the nodal battery life and the duration of paths while CMDR minimized the total transmission power consumed per packet. The metric was good at reflecting the current dissipation of energy without considering other traffic measurements including queue length and the number of connections passing through the nodes.

Using dynamic source routing (DSR) protocol for conducting experimental evaluations, MDR and CMDRwere compared against prior proposals for power-aware routing.It wasshown that using the drain rate for power-aware route selection offered superior performance results as it avoided overdissipation i.e. in situations in which a few nodes allowed too much traffic to pass through them simply because their remaining battery capacity was temporarily high.

47. Adaptive Quorum-based Energy Conservationin MANET

The lifetime of a Mobile Ad hoc Network (MANET) depends on the durability of battery resources of the mobile hosts. In the IEEE 802.11 power saving mode, a host must wake up at every beacon intervalto check if it should remain awake. Such a scheme fails to adjust the host's sleep duration according to its traffic, thereby reducing its power efficiency.Chih-Min Chao et al. (2006) studied a new MAC protocol for power saving options in MANET (Single Hop). They stated that the protocols’ quorum-based sleep/wakeup mechanism conserved the energy by allowing the host to sleep for more than one beacon interval when some transmission operations were being performed. The main idea of this system was to extend the sleep duration of the host in order to conserve each node’s power, thus allowing the extension of MANET lifetime. The outcomes showed that their expected goal was reached with this proposed algorithm and the authors planto extend the protocol and using it with multi-hop MANETs would be viable while keeping the end-to-end delay ratio tolerable.

48. An Energy-efficient CommunicationScheme for Mobile Ad hoc Networks

In MANETs, every node overhears every data transmission occurring in its vicinity and thus, consumes energy unnecessarily. However, since some MANET routing protocols such asDynamic Source Routing (DSR) collect route information via overhearing, they would suffer if they are used in combination with 802.11 PSM. Allowing no overhearing may critically deteriorate the performance of the underlying routing protocol while unconditional overhearing may offset the advantage of using PSM.

Sunho lim et al. (2009) investigated a new communication mechanism which they referred to asRandomCast. The scheme saved energy by reducing redundant rebroadcasts for a broadcast packet; it was used by the sender to specify the desired level of overhearing to make a prudent balance between both the energy and routing performance. The results confirmed that the proposed algorithm was highly energy-efficient compared to conventional 802.11 as well as 802.11 PSM-based schemes in terms of total energy consumption, energy goodput, and energy balance. The researchers planned further to incorporate the concept of Random-Cast within other routing protocols.

49. Routing Based on Grover's Searching Algorithm for Mobile Ad hoc Networks

In Mobile Ad hoc Network, routing protocols directly affect various indices of network Quality of Service, thus, playing an important role in network performance. To address the drawbacks of traditional routing protocols in MANET, such as poor anti-fading performance and slow convergence rate for basic Dynamic Source Routing (DSR), Meng Limin and Song Wenbo (2013) were motivated todesign a new protocol based on Grover's searching algorithm.Each node maintained a node vector function and all thenodes could obtain a node's probability vector using Grover's algorithm and then select an optimal route according to the node's probability. Compared to DSR, the proposed protocol was very effective in reducing both the number of routing hops and network delay, thus, increasing the whole network lifetime and performance. It also significantly improved the anti-jamming capability of the network.

50. Mobility-aware Energy Efficient Job Scheduling using Genetic Algorithm in Mobile Grids

A grid is defined as a system that solves large-scale problems in dynamic virtual coordinate resources that are not subjected to centralized organizations. Mobile grid integrates traditional wired grid controlwhich uses standard, open, and general-purpose through the wireless channel to share grid resources to protocols and interfaces so as to deliver nontrivial qualities of mobile users or provide resources to a grid. The extension of the grid to mobile computing has advantages over fixed computing resources such as making it available to the users even when they are mobile.

As in mobile grids, the existing job scheduling scheme causes increased energy consumption. In addition, there is reduced network performance and efficiency, G. Saravanan et al. (2014) attempted a study on a mobility- aware energy efficient job scheduling using the genetic algorithm in mobile grids. They grouped the jobs according to the available routes by splitting them into subtasks and priorities and then scheduled thembased on various parameters namelymobility, resource availability, job completion time, and energy. They used another mechanism; the mobility prediction algorithm efficient in accurately estimating the node's movement. The simulation outcomes proved that the proposed algorithm was efficient in minimizing the energy consumed during the transmission processeswhich then resulted in the enhancement of the whole network performance.

51. An Efficient and Energy-aware Clustering Scheme forOLSR Protocol

Integrating the Quality of Service (QoS) in a Mobile Ad hoc Network (MANET) is a difficult challenge and a very tedious task. It requires finding a compromise between several QoS parameters. The energy criterion is one of the most important of these parameters that will provide a long lifetime for a given MANET.

Loutfi and Elkoutbi (2015) conducted a study on an algorithm capable of managing the power consumed by the mobile nodes during the transmission processes and could enhance the transmission delay. The protocol provided various enhancements in MANETs such as enhancing the ability to select various cluster heads, managing the mobility and density of the nodes. Their research mainly consisted of electing various cluster heads to provide the hierarchical routing scheme using the Optimized Link State Routing Protocol (OLSR). It also aimed at increasing the network lifetime by taking each node’s residual energy into consideration during the route discovery processes before the packet transmission started. To confirm the effectiveness of their research work, they conducted a comparative evaluation of their proposed scheme with the already existing ones in the literature. The outcomes of their research confirmed that the proposed algorithm was efficient in optimizing the end-to-end delay which could be attributedto the selective forwarding approach based on the hierarchical routing model. In future, their research would be improved bycombining energy with other criteria such asdensity and mobility to produce more efficient clustering. The authors also stated their intent to experiment the impact of differentiated traffic namelyQoS classes i.e. real-time, best-effort, and overlapped clustering i.e. one cluster per QoS class.

52. Mobility and Energy-aware Clustering forConstructing Stable MANETs

Node clustering is a technique to mitigate the topology changes in MANETs. It stabilizes the end-to-end communication paths and maximizes the path lifetime. It also improves the network scalability such that the routing overhead does not become tremendous in large-scale ad hoc networks. Its effectiveness, however, depends largely on the cluster stabilitywhich is measured by the lifetime of the cluster heads and the membership time of the cluster members. The existing clustering algorithms do not achieve this objective well.

Xu and Wang (2006) first pointed out how clustering the network would be a fundamental issue to be taken into account while designing a robust network by enumerating various advantages provided by this technique. A new clustering mechanism was then proposed; MEACA (Mobility and Energy Aware Clustering Algorithm for Constructing Stable MANETs)which considered both the node mobility and energy information. The cluster’s stability was maximized since the nodes with the low-mobility and high-energy were selected as cluster heads and were kept unchanged to the extent of their maximum possible lifetime. The proposed scheme was very effective in both small and large MANETs. The proposed algorithm would be investigated for advantages provided by the clusters’stabilization technique with respect tothe end-to-end communication performance such asthe packet’s throughput and delay.

53. Energy-efficient Stable Routing using QoS Monitoring Agents inMANET

As providing a reliable and stable route is a prominent issue concerned with MANETs, a stable and energy-efficient routing technique was studied by Palaniappan and Chellan (2015).OoS monitoring agents were used to collect and calculate each link reliability metric namelyLink Expiration Time (LET), Probabilistic Link Reliable Time (PLRT), Link Packet Error Rate (LPER), and Link Received Signal Strength (LRSS). Furthermore, the authors considered the Residual Battery Power (RBP) to maintain the energy efficiency in the network. Route Selection Probability (RSP) was finally calculated based on those estimated parameters and using the fuzzy logic technique. The outcomes of their investigation revealed that their proposed routing scheme increased the packet delivery ratio and reduced energy consumption.

2.1.7 Security in MANET

Security is a paramount concern in Mobile Ad hoc Networkbecause of its intrinsic vulnerabilities. These vulnerabilities are inherent to MANET andcannot be avoided.As a result, attacks with malicious intents have been and will be devised to exploit these vulnerabilities and to cripple MANET operations. In the following section, some existing security problems in MANET and a few promising research directions are presented. On the prevention side, various key and trust management schemes have been developed to prevent external attacks from outsiders, and various secure MANET routing protocols have been proposed to prevent internal attacks originated from within the MANET system. On the intrusion detection side, new intrusion detection frameworks have been studiedespeciallyfor MANET. Both prevention and detection methods work together to address the security concerns in MANET.

54. A Multitier Adaptive Military MANET Security Approach using Hybrid Cryptography and Signcryption

To provide high security and performance in military MANETs, a new multi-tiered adaptive military MANET security protocol based on hybrid cryptography and signcryption was studied by Attila et al. (2010). The protocol inculcated novelties instructural design, cryptographic methods, and the use of hybrid key management techniques in military MANETs. The structural design of this protocol differed from the traditional UAV (unmanned aerial vehicles)-MBN (mobile backbone nodes)networks with MBN1-MBN2 tierwhich exploited the heterogeneity of MBN tier and tampered the resistance property of MBN1 nodes in modern armies. It used a new multi-leveled security approach based on efficient cryptographic primitives. Another feature included in this protocol was multi-tiered independent ELK (Efficient Large Group Key) theater mechanism. The hybrid key management approach integrated Iolus type decentralized techniques with ELKbased centralized techniques in a hierarchical and modular manner. The protocol achieved both high security and efficiency simultaneously in large and dynamic military MANETs. Authors finally stated that in future works, they would consider addressing the secure routingwhich is another challenging problem in military MANETs.

55. Efficient Monitoring of Intrusion Detection in Mobile Ad hoc Networks using Monitoring-based Approach

MANET being an infrastructureless wireless network, nodes can freely communicate without a central coordinator; various problems may arise such assecurity breaches into the network caused by malicious nodes acting as normal nodes leading tothe network misuse. To deal with this problem, various Intrusion Detection Techniques (IDTs) have been proposed for Mobile Ad hoc Networks. Kumaret al. (2013) conducted quantitative evaluations of false positives and their impacts on monitoring-based intrusion detection for ad hoc networks. Experimental results showed that even for a simple three-node configuration, an actual ad hoc network suffered from high false positives; these results were validated by Markov and probabilistic models. However, this false positive problem could be observed by simulating the same network using popular ad hoc network simulators, such as NS-2, OPNET, or Glomosim. To resolvethe issue, a probabilistic noise generator model was implemented by using a sliding window-based monitoring approach. With that revised noise model, the simulated network exhibited the aggregate false positive behavior similar to that of the experimental testbed. Simulations of larger (50-node) ad hoc networks indicated that monitoring-based intrusion detection had very high false positiveswhichcould reduce the network performance or increase the overhead. The final results revealed that in a simple monitoring-based system where no secondary and more accurate methods were used, the false positives influenced the network performance in two ways: reduced throughput in normal networks without attackers and inability to mitigate the effect of attacks in networks with attackers.

56. Detection of Intruders in Mobile Ad hoc Networks

Mobile ad hoc networking has become an exciting and important technology in recent years because of the rapid proliferation of wireless devices. However, it is highly vulnerable to attacks due to the open medium, dynamically changing network topology, cooperative algorithms, and lack of centralized monitoring and management point. The security of data becomes more important with the increased use of commercial applications over wireless network environments. There areseveral problems of security in wireless networks due to different types of attacks and intruders. There are a lot of security attacks in MANET and DDoS (Distributed Denial of Service) is one amongthem. To reveal the effect of DDoS on routing load, packet drop rate, end-to-end delay, P.Ravi Kumar and Kanthi Kiran (2013) conducted their research on mobile ad hoc network routing vulnerability and analyzed the network performance against attacks. The resistive schemes against attackswere proposed for Ad hoc On-demand Distance Vector (AODV) routing protocol and their efficacies were validated. While implementing the proposed system, the md5 algorithm was used for providing security against attacks and intruders. For secure transmission, the network layer was secured using RSA algorithm for the transmission of each data packet in the network. In the proposed scheme, by comparing all the messages passing at each node, the repeated IPs in the network were identified.Whenever compared messages were identical, theywere immediately considered as security breaches.

57. The Evolution of IDSSolutions in Wireless Ad hoc Networks to Wireless Mesh Networks

The domain of wireless networks is inherently vulnerable to attacks due to the unreliable wireless medium and such wireless networks can be secured from intrusions using either prevention or detection schemes. Novarun Deb et al. (2011) conducted their study on intrusion detection rather than on the prevention of attacks. The authors stated that as attackers would keep on improvising, a single active prevention method alone cannot provide total security to the system;hence, several IDS solutions have been previously proposed. Their research work was an extension ofa survey on IDS solutions for MANETs and WMNs published earlier in the sense that the present survey would offer a comparative insight of the recent IDS solutions for all the sub-domains of wireless networks. They conducted a comprehensive review of the passive security mechanism of Intrusion Detection System (IDS) for different types of wireless ad hoc networks with more than fifty different IDS approaches being cited in their study. The authors finally stated that the study might be extended to review recent works on cross-layer IDS architecture, security for underwater ad hoc networks, etc. as those workswerebeyond the scope of their published article.

2.1.8Network Clustering Mechanisms

Clustering in Mobile Ad hoc Networks (MANETs) has many advantages compared to traditional networks. Nevertheless, the highly dynamic and unstable nature of MANETs makes it difficult for the cluster-based routing protocols to divide a mobile network into clusters and determinecluster heads for each cluster. In recent years, several routing protocols and cluster-based protocols have been proposed for mobile ad hoc networks.

The following section presents some of the clustering mechanisms proposed in the literature.

A. Mobility-aware Clustering in MANETs

With mobility-aware clustering, the node mobility behaviors (distance, speed, acceleration, and relative velocity) are first estimated at regular intervals of time. By using the estimated mobility behavior, geographically adjacent mobile nodes are grouped into a cluster, and the node having the low mobility or low relative velocity is selected as a cluster head. The mobility-aware clustering structure improves the network stability by reducing the least cluster head change, a number of re-affiliations, and association loss (Kumar et al.2013). Most of the recent researches in MANETs are focused on mobility-aware clustering algorithms. Some are discussed in the following section:

58. A Mobility Prediction-based Clustering Scheme for Ad hoc Networks

Ni et al. (2011) conducted their research study on a Mobility Prediction-Based Clustering (MPBC) scheme for ad hoc networks with high mobility nodes where a node might change the associated Cluster Head (CH) several times during the lifetime of its connection. The proposed clustering scheme includes an initial clustering stage and a cluster maintaining stage. The Doppler shifts associated with periodically exchanged Hello packets between neighboring nodes were used to estimate their relative speeds, and the estimation results were utilized as the basic information in MPBC. In the initial clustering stage, nodes having the smallest relative mobility in their neighborhoods were selected as the CHs. In the cluster maintaining stage, mobility prediction strategies were introduced to handle various problems caused by node movements, such as possible association losses to current CHs and CH role changesfor extending the connection lifetime and providing more stable clusters. An analytical model was developed to find the upper and lower bounds of the average connection lifetime and to find the average association change rate of MPBC. Numerical results verified the analysis and further showed that the proposed clustering scheme outperformed the existing clustering schemes in ad hoc networks with high speedy nodes.

59. A Mobility-based Metric for Clustering in Mobile Ad hoc Networks

Basu et al. (2001) made a research study on a novel mobility metric for Mobile Ad hoc Networks (MANET) that is based on the ratio between the received power levels of successive transmissions measured at any node from all its neighboring nodes. This mobility metric was subsequently used as a basis for cluster formationwhich could be used for improving the scalability of services such as routing in such networks. They proposed a distributed clustering algorithm, MOBIC, based on the use of the mobility metric for selection of clusterheadsand demonstrated that it led to more stable cluster formation than the Lowest-ID clustering algorithm (least cluster head change)which is a well-known clustering algorithm for MANETs. They showedthe reduction of as much as 33% in the number of clusterhead changes owing to the use of the proposed technique. In a MANET that used scalable cluster-based services, the network performance metrics such asthroughput and delay were tightly coupled with the frequency of cluster reorganization.

B. Energy-efficient Clustering in MANETs

Energy is an important factorwhich directly affects the lifetime of networks, for example, the energy constraints where some nodes are dead due to their low battery powerresulting in degradation of the whole network performance. To avoid such kinds of problems, a network is divided into clusterswhich optimize the energy consumption as the best paths are detected in terms of energy to be used by a stream of data **(**Choukri et al. (2014)).

The energy-efficient clustering mechanisms are presented in the following section:

60. Flexible Weighted Clustering Based on Battery Power for Mobile Ad hoc Networks

Hussein et al. (2008) investigated an efficient power-aware clustering algorithm; the Flexible Weighted Clustering Algorithm based on Battery Power (FWCABP). The scheme led to a high degree of stability in the network, minimizing the number of clusters and the overhead for the clustering formation and maintenance by keeping a node with weak battery power from being elected as a cluster head. The performance of the algorithm was also evaluated in terms of the number of clusters formed, re-affiliation frequency, andthenumber of cluster head change. Results showed that the new scheme performed better than the existing ones and was also tunable to different kinds of network conditions.

61. Conserving Energy in Wireless Ad hoc Networksusing Location and Cluster-based Schemes

Xu et al. (2003) attempted a study on two topology-control protocols that extended the lifetimes of dense ad hoc networks while preserving connectivity and the ability for nodes to reach each other. Those proposed protocols conserved energy by identifying redundant nodesand turning their radios off. Geographic Adaptive Fidelity (GAF) identified redundant nodes by their physical location and a conservative estimate of radio range. It controlled node duty cycle to extend network operational lifetime while maintaining network connectivity, independent of the involvement of ad hoc routing protocols. GAF could substantially conserve energy (40% to 60% less energy than an unmodified ad hoc routing protocol) allowing the network operational lifetime to increase in proportion to node density. Cluster-based Energy Conservation (CEC) directly observed radio connectivity to determine redundancy and therefore, could be more aggressive at identifying duplication and more robust to radio fading. The results through testbeds showed that the protocols were robust to variances in node mobility, radio propagation, node deployment density, and other factors.

62. Energy Efficient Routing using Max-Heap Tree-based Structured Cluster for MANETs

Madhvi et al. (2014) studied an algorithm, Max-Heap tree algorithm, an energy-aware clustering algorithm for longer life of MANET that selected an efficient cluster head with the help of the Max-heap tree. The clusters were designed using max-heap on the basis of energy level; the node which had the highest energy in the cluster would act as a cluster head until its energy level became equal to or less than the threshold value. The battery of the cluster head would never exhaust, hencethe working of cluster did not suffer due to CH services, in turn, the network wouldsustain for a longer duration.

C. Connectivity-based Clustering in MANETs

The connectivity-based method mainly focuses on the selection of a particular node as a head node based on the neighborhood connectivity. The based method with its load balancing efficiency calculates the efficient cluster head with the help of the number of mobile nodes connected.

63. TheHighest Connectivity Clustering Approach

Clustering algorithms help organize mobile ad hoc networks in a hierarchical manner and have various features. A cluster-based MANET has many important issues to examine such asthe cluster structure stability, the control overhead of cluster construction and maintenance, the energy consumption of mobile nodes with different cluster-related status, the traffic load distribution in clusters, and the fairness of serving as cluster heads for a mobile node.

Highest Connectivity Clustering algorithm (HCC)studied by Agarwal and Motwani (2009) is ascheme in which the degree of a node was computed based on its distance from others. Each node broadcasts its ID to the nodes that are within its transmission range. The nodewith the maximum number of neighbors (i.e., maximum degree) is chosen as a cluster head. The neighbors of a cluster head become members of that cluster and can no longer participate in the election process. Since no cluster heads are directly linked, only one cluster head is allowed per cluster. Any two nodes in a cluster are at most two hops away since the cluster head is directly linked to each of its neighbors in the cluster. Basically, each node either becomes a cluster head or remains an ordinary node.

Thesystem has a low rate of clusterhead change but the throughput is low. Typically, each cluster is assigned some resourceswhich areshared among the members of that cluster. As the number of nodes in a cluster is increased, the throughput dropped. The reaffiliation count of nodes is high due to node movements and as a result, the highest-degree node (the current cluster head) may not be reelected to be a cluster head even if it loses one neighbor. All the drawbacks occur because the approach doesnot have any restriction on the upper bound forthe number of nodes in a cluster.

D. Weighted Clustering in MANETs

Algorithms of this type usually consider four parameters for the cluster head selection criteria. Theseparameters arethe degree-difference calculated for every node, distancesummation which is defined as the sum of distances from a given node to all its neighbors, mobilitywhich is taken by computing the running average speed of every node during a specified time T and the remaining battery power.

64. A Weighted ClusteringAlgorithmfor Mobile Ad hoc Networks

Chatterjee et al. (2002) conducted a research study on an on-demand distributed clustering algorithm for multi-hop packet radio networkswhich tookthe ideal degree, transmission power, mobility, and battery power of mobile nodesinto consideration. In the algorithm, the time required to identify the cluster heads depends on the diameter of the underlying graph. The number of nodes in a cluster was kept around a pre-defined threshold to facilitate the optimal operation of the Medium Access Control (MAC) protocol. The non-periodic procedure for cluster head election was invoked on-demand and aimed to reduce the computation and communication costs. The cluster heads operating in “dual” power mode connected the clusters which helped in routing messages from a node to any other node. Authors observed a trade-off between the uniformity of the load handled by the cluster heads and the connectivity of the network. The results showed that the algorithm performed better than the existing ones and was also tunable to different kinds of network conditions.

CHAPTER 3

QoS-AWARE TRANSMISSION FOR MULTIMEDIA APPLICATIONS IN MANET USING ACO WITH FUZZY LOGIC

The prominent advantages of ad hoc networks have prompted the fast development of multiple wireless applicationswhich have been used in various domains such as education, entertainment, commerce, emergency services, military fields, etc. Different Wi-Fi enabled mobile devices especially laptops, handheld devices such assmartphones and tablet are frequently used in our daily life nowadays. For example, Li and Shen (2014) stated thatthe use of wireless connections to access the Internet in the US would be increased upto 207 million users in 2017. Owing to the regularly increasing popularity of mobile devices, MANETs'daily demands and requirements proportionally augment.

MANET is generally an infrastructureless network with no need to configure a central manager such as a router, access point, etc. Nodes are mobile in nature, hence, MANET topology is dynamic (Arti et al.(2014)). Due to MANETs'self-organizing nature, bandwidth is sometimes constrained and to address this, a virtual backbone network is sometimes configured. This type of network is defined as spin playing a major role in routing, connectivity management, and broadcasting operations. Moreover, routing protocols are one amongthe other issues of concernas they play an important role in achieving high QoS (Quality of Service); a major factor in evaluating MANET routing performance.

Different routing protocols have been proposed for MANET; they use probe packets to detect path cost. The cost contains information about the calculated delay, the number of available hops, and the total number of packets lost along the way through that path. This information traverses throughout the network and is then used in creating and maintaining the routing tablewhich in turn helps in selecting the best suitable route to successfully relay packets from the source node to the destination node (Vigita and Julie (2013)). Routing failures sometimes occur due to the mobility of nodes, unpredictable and dynamically changing network topology, and the prompt networkdisconnectivity events. Each node in MANET usually acts as a routerwhich frequently forwards data packets to the end devices. In addition to the previous routing-related issues, MANET faces other various problems such asvariable networkcapacity, security-related issues, intermittent connectivity, battery power and processes constraints, unreliable links, and hidden terminal problems (Zaghar andWahab (2013)). To efficiently route in MANET, protocol designers have developed various routing algorithmswhich addressthose frequent MANET-related challenges.

Despite those previously mentioned problems, MANETs provide numerous advantages compared to other types of networks.Being a self-organizing and infrastructureless wireless network makestheaccess to the network and data easier at anytime and anywhere. Thanks to those advantages, its applications are enormous especially, in environments where there are high demands of QoS provisions. QoS is evaluated based on some network parameters such as throughput, PDR (Packet Delivery Ratio), jitters, delay routing metrics, etc.

Depending upon the type of application being used and the end user requirements, QoS parameters are sometimes varied. QoS is an essential issue to be taken into account while implementing a new routing protocol, for example, an efficient routing protocolwhich focuses on providing solutions to QoS-related problems is also able to maintain the throughput and packet delivery ratio high during the overall packet transmission processes.

All those achievements are possible with the help of various QoS techniques such asACO (Ant Colony Optimization) algorithm discussed by Nancharaiah and Mohan (2013)which was the most proposed by various researchers for QoS-related matters in MANET. In addition, a number of proactive, reactive, hybrid protocols, and fuzzy logic techniques were presented by Khanpara (2014)where the fuzzy logic theories were applied for providing high QoS in MANET. Despite all these efforts, none of them has provided full-featuredQoSfor efficient routing in MANETs.

In this chapter, the design, implementation, and appraisal of the QoS framework that supports multimedia applications in MANET is presented. A key basic of the proposed QoS framework is the Ant Colony with Fuzzy optimization technique used in combination with three different parameters namelyResidual energy (Re), Distance (Dt), and Reachability (Rc). Those parameters are the most important and popular QoS measurement metrics available in MANETs and are collected at each node.Additionally, another prominent techniqueis used; the fuzzy logic system which is a mechanism of logic computing based on the “degree of truth” instead of using Boolean logic values; 1 for True and 0 for False. The technique helpsto process the input values in order to determine the degree at which a node is located throughout the network, thus, making a good decision in selecting the best route which packets should pass through. To achieve this, it generates 27 rules using those three input values. Thoserules are then used to fix a probabilistic value for each pathwhich determines whether the route can be selected as an optimal path or not. The path selection is performed by a F_ANT during the route discovery process.

3.1 QUALITY OF SERVICE [QoS]

The Quality of Service is a set of service requirements to be met by the network while transporting a packet stream from the source to the destination. The intrinsic notion of QoS is an agreement or a guarantee by the network to provide a set of measurable of pre-specified attributes to the end-user in terms of the end-to-end performance i.e. delay, delay variance (jitter), bandwidth, probability of packets loss, power consumption, service coverage, etc. The goal of QoS provisioning is to achieve a more deterministic network behavior so that information carried by the network can be rightly delivered and network resources are better utilized. In order to provide the QoS, a more sophisticated QoS-routing protocol is required.

The primary goal of QoS-aware routing protocols is to determine a path from the source to the destination that satisfies the needs of the desired QoS. The QoS-aware path is determined within the constraints of bandwidth, minimal search, distance, and traffic conditions. Since the path selection criterion is based on the desired QoS, the routing protocol can be termed as QoS-aware.

3.2ANT COLONY OPTIMIZATION [ACO]

Swarm Intelligence (SI)is a collective behavior ofdecentralized, self-organized systems either natural or artificial. This concept is regularly used in artificial intelligence technology as it is one of the best mechanisms used for solving very complicated issues. ACOis a prominent Swarm Intelligence approach; a class of optimization algorithms modelled based on the organization of an ant colony. It is built based upon the real world ant behaviors.Being a probabilistic technique, it is very useful in solving problems that deal with finding better paths using graphs.

Artificial 'ants' -simulation agents- locate the optimal paths by moving through parameter spacerepresenting all possible solutions. Natural ants lay down pheromones directing each of them to resources while exploring their environments. The simulated 'ants' similarly record their positions as well as the quality of their solutions to the optimal pathfinding problems. Those recordings play an important role in later simulation iterationsas they are used by the future ants to achieve better outcomes.

For example, ants initially use random walk approach when multiple paths are available between their nest and the food. During this process, each ant lay pheromone in the path forward from the nest to the food as well as backward from the food to the nestwhich aids to find out the most visited path by an ant. ACO, a prominent swarm intelligence mechanism is based on this ants' natural behavior in finding a path towards the desired food.

This algorithm has been designed to find out the best path using the pheromone deposited by the ants. Upon getting the food, they go back to their nests; during this returning-back process, they simultaneously deposit new pheromone along the route back to their nest. The existing pheromone is then updated along the way but starts weakening by evaporation as the time passes. Different ants continuously move to the destination node to find out any low cost and a feasible path from that node to the source. Each of them considers two parameters in order to select the next hop to pass through. The first one is the total amount of pheromone deposited along the path towards the next node, the second one is the queue length associated with the followed link. Figure 3.1 presents the process of an ant colony optimization routing protocol.

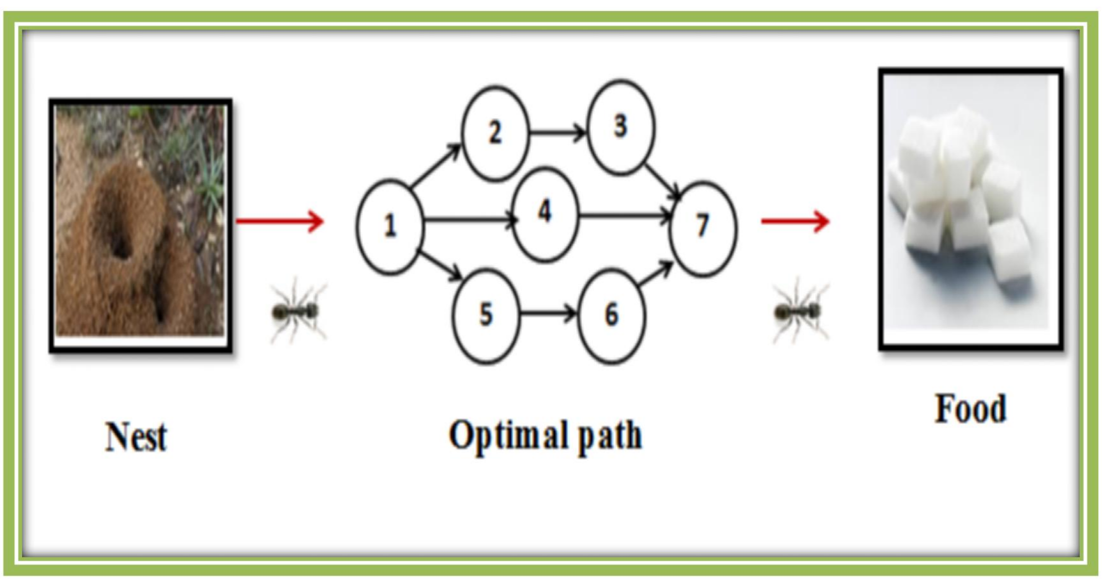


Figure 3.1 Ant Colony Optimization techniques

3.3 FUZZY LOGIC SYSTEM [FLS]

Fuzzy logic is a form of many-valued logic in which the truth values of participating variables may range between 0 and 1 as opposed to Boolean logicwhere those values are either 0 or 1. This system has beenenhanced to handle the concept of partial truth values ranging between completely true or completely false while imprecise functions are used to manage linguistic variables. Based upon the quality of rules, the fuzzy imprecision is varied. The fuzzy logic system results will change depending upon time. It is a linguistic system for definite ruleswhich are defined in the form of IF-THEN conditions and some Boolean operations; OR, NOT, and AND operators. The fuzzy logic systems are usually used in artificial intelligence applications such as medical diagnosis, subway control system, stock trading, weather forecasting system, knowledge-based system, controlling unmanned military vehicles, and pattern recognition. Those types of systems are mainly composed of four constituents namely the Fuzzifier, Defuzzifier, Fuzzy Rule Base, and Fuzzy Inference Engine. These components are arranged as shown in Figure 3.2 in any Fuzzy Logic System.

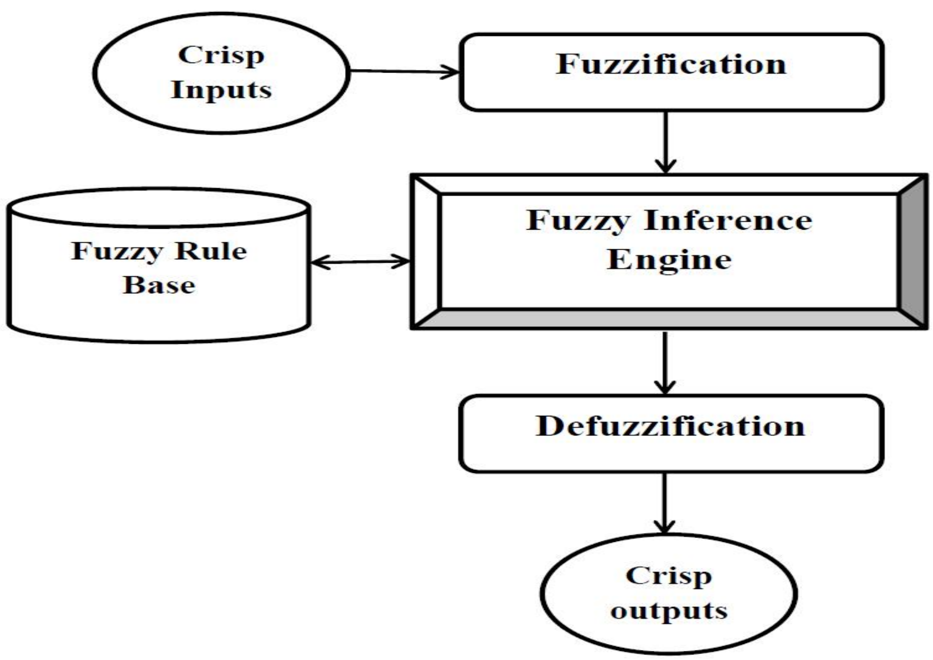


Figure 3.2 Fuzzy Logic System

3.3.1Processes of the Fuzzy Logic System

The first processwhich takes place in the FLSis the fuzzification operation. Here, the fuzzifier receives the input value called crisp or numeric value. This value is then converted to the corresponding fuzzy value according to the rules used to provide the results defined for these fuzzy inputs. All those operations are performed by the Fuzzifier, the Fuzzy Inference Engine's role then begins by computing the set of outputs based on IF-THEN rules defined in the Fuzzy Rule Base. The AND operator is required to combine the set of different rules. The defuzzification process is the last operation performed by Fuzzy Logic Systemwhich finally converts the fuzzy output values into their corresponding crisp values.

3.4 METHODOLOGY

In the proposed scheme, QAMACF (QoS-Aware transmission for Multimedia applications using Ant Colony with Fuzzy optimization), both theAnt Colony Optimization technique and the Fuzzy Logic approach are combined. It is mainly aimed at achieving high Quality of Service for efficiently performing multicast transmission of multimedia files in MANET.In accordance, a stable and a reliable pathis selected with high-link connectivity. The proposed algorithm is explained in detail in the following section.

3.4.1 Frameworkfor QAMACF

For implementing the proposed algorithm, ACO technique is combined with the fuzzy logic system as abovementioned. The performance evaluation is conducted using a variety of parameters namelyResidual energy (Re), Distance (Dt), and Reachability (Rc); the multicast transmission approach for multimedia data is used to speed up route discovery process. The mesh-based multicast structure is used as it isadvantageous compared to tree-based protocols; it provides redundant routes for maintaining connectivity to the group members, in turn, alleviating the low packet delivery ratio problemcaused by link failure events (Patturose and Vinoth (2013)). They are robust because they effectively deal with the dynamicity of nodemobility. Multicast transmission usually consists of the following three major phases:

- Group Construction phase
- Route Construction phase
- Group Maintenance phase.

a) Group Construction Phase

Group construction phase is the first stage of the multicast transmission process in MANETs. QAMACF, first of all,constructs a multicast group of nodes for packet transferring purpose. The group is created in the following manner: Generally, a sender initially floods a join message to all the nodes in the network. Interested nodes replyto the sender via the reverse paths. When the reply message reachesthe sender node, the membership of the replying node is immediately accepted.

There may be simultaneous senders, the first sender then floodsa join message with data payload piggybackedwhich isperiodically flooded throughout the entire network to refresh the membership information and thenupdates any relevant multicast path. An interested node will respond to the join message. The multicast paths built by that sender are shared with the other senders. The source node isthe first member of the group; intermediate nodes regularly forwardthe multicast packets from not only that sender but also from other senders available in the same group.

Among the forwarding nodes, some nodes are available in the routing structure that are not interested in multicasting packets but play router's role by intelligently forwarding packets to receivers; those are referred to'forwarders or forwarding nodes'. Group members (senders, receivers, and forwarding nodes) are called mesh nodes; a node (for example node 'y') isan upstream (parent) or a downstream (child) node of any other given node (node 'x') if it iscloser or farther away from the root of the tree than the node x.

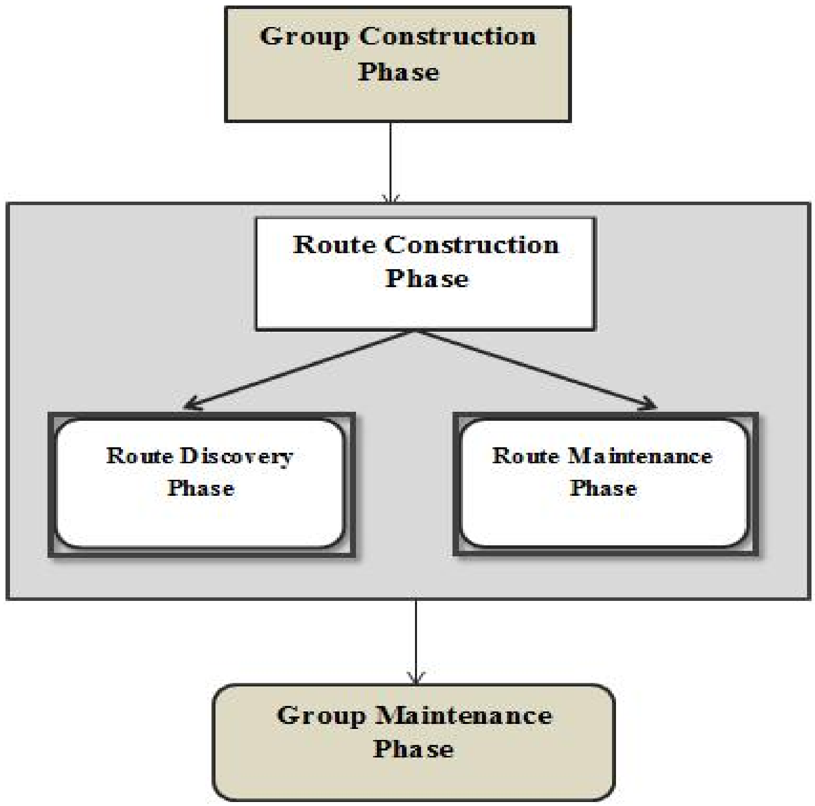


Figure 3.3 Route and group construction processes in MANETs

b) Route Construction Phase

The second phase deals withthe route construction process. Upon completing the group constructing operations in the first phase, with the help of the multicast group, a route between any source and destination node pairs isfound; ACO with fuzzy logic is used for this end in order to achieve high QoS for efficient multicast routing of multimedia data. In the second phase, two different processes are performed in order to select an optimal path namelyroute discovery phase and route maintenance phase.

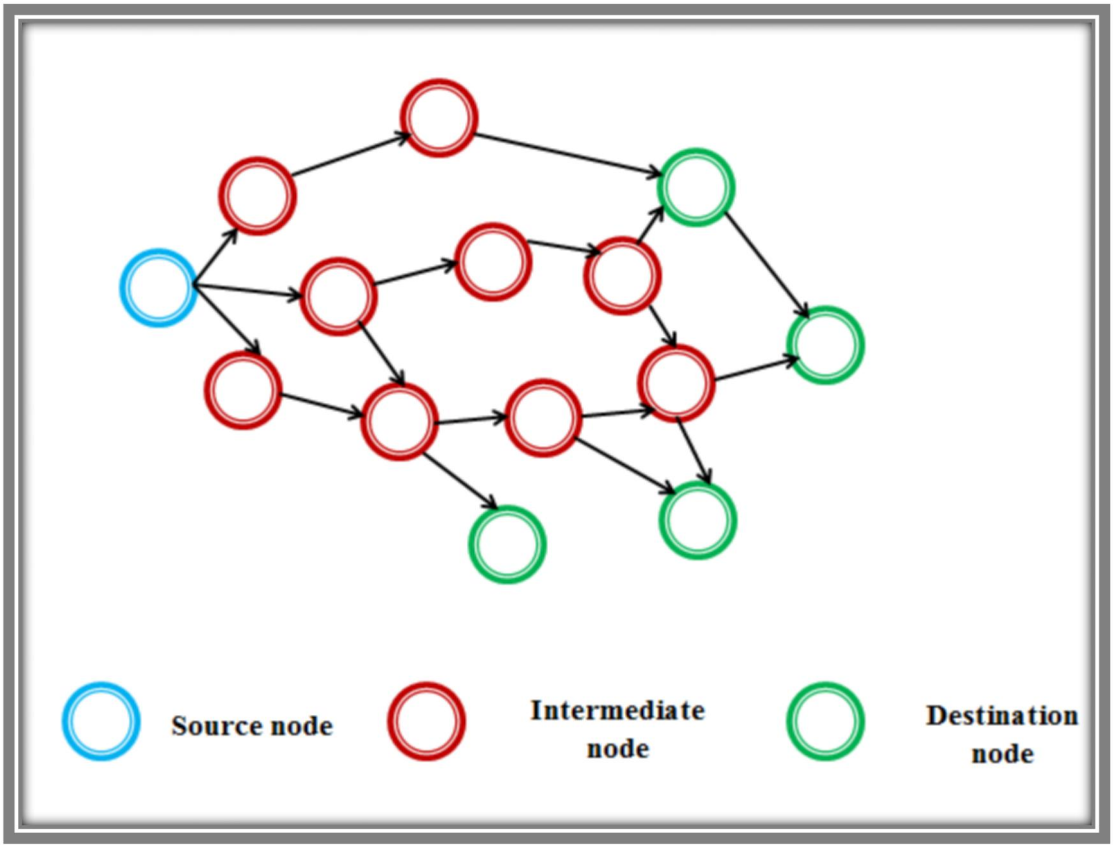


Figure 3.4 Multicast transmissions in MANET

During the route selection process, each node sends a beacon message to its neighbor node. It consumes some amount of energy; nodes playing router's roles will consume some more energy compared to ordinary nodes because they arein an active state during the overall period of the packet transmission process. To this end, it is needed to find out the residual energy of each node during the route selection process. The residual energy and distance arethe very important metrics for the operation. For example, when the distance between any two participating nodes located along the route toward the destination node ishigh, the network link passing through that particular node's route is weak and will be easily broken due to the frequent mobility of the nodes. The distance between any two nodes iscalculated by using Euclidean distance function formula (Li and Shen (2014)):

$$\boldsymbol{D}=\sqrt{(x_1-x_2)^2+(y_1-y_2)^2} \qquad (3.1)$$

Inequation (3.1), the variables x_1 and x_2 are the x-coordinates and y_1 and y_2 are they-coordinatesof nodes A and B, respectively. Using the above equation, the distance between the two nodesis calculated (Yassein et al. (2005)). The Reachability parameter isthen calculated using equation (3.2).

$$R = (N\text{-}1)\ 0.8\ (\pi r^2 / A) \qquad (3.2)$$

- ✓ *R* refers to the Reachability of a node,
- ✓ *N*is the number of available mobile hosts, while *A* refers to the area (surface) occupied by the node,
- ✓ *r* refers to the node's coverage range.

a) Route Discovery phase

At this stage, a route isdiscovered between a pair of nodes. A source node isconnected to a destination node through intermediate nodes during this route discovery process. The following steps areused to discover the route:

i. The source node multicasts a hello message to each of its neighbor nodes.
ii. The forwarding node,*ANT (F_ANT)* then forwards that message to other nodes.
iii. During this process, *F_ANT*collectsinformation related to residual energy, distance, and reachability of each node.
iv. Upon reaching the destination, *Backward ANT (B_ANT)*follows the same path inthe reverse direction.
v. The informationcollected by the *F_ANT* is used as input to the fuzzy logic system.
vi. The fuzzy logic system then generates27 rules based on those three input parameter metrics.
vii. By manipulating those rules, an optimal path is selected based on the probabilistic values obtained by evaluatingeach of the available routes using QoS parameters.
viii. The process is repeated till the end of the session (when the most optimal path is found to route packets through).

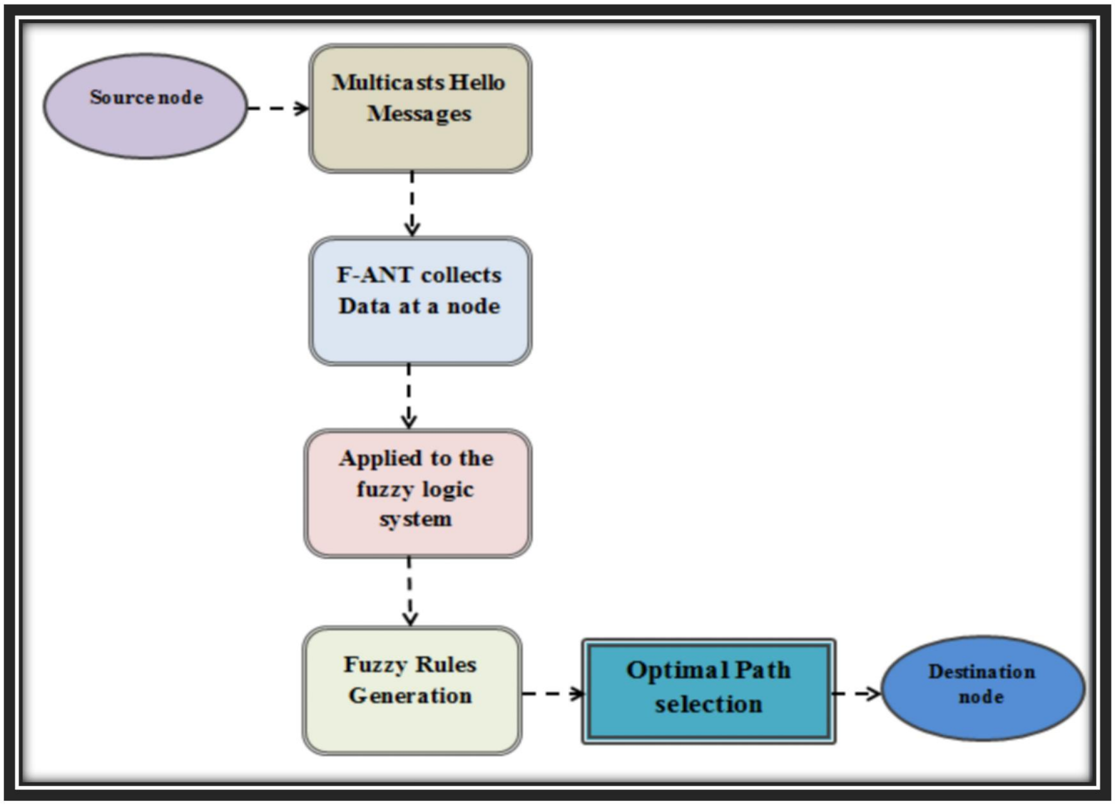


Figure 3.5 Route Discovery Process using QAMACF

Figure 3.6 presents the route discovery process of QAMACF, after which multimedia data transmission operations will immediately start. It is also evident that *F-ANT* packet header contains information related to the QoS routing parameters; *Residual energy (Re), Distance (Dt),* and *Reachability (Rc)*.

```
Inputs: Rs, Dt, Rc
  Initialization: I= {Rs→ Φ; Dt→ Φ; Rc→ Φ}
    Begin
        Execute _RD()
 Forward_F_Ant()
        Visit neighbor node
if (Curr_id=Dest_id)
break
else calculate I from equation (1) and equation (2)
then assign I→FLS
end if
CheckFRL()
Begin
if (P==H || P==VH)
then curr_node →selected
else if ((P==VL) || (P==L) || (P==M))
then curr_node → rejected
end if
end if
    End
recall _RD()
 End
Output: the optimal route is selected
```

Figure 3.6 Pseudocode for Route Discovery Process

For route discovery purposes, the QoS input parameters i.e. *Residual energy (Re), Distance (Dt),* and *Reachability (Rc)* are initially set to null (Φ) values. Table 3.1 exhibits the meaning of symbols and notations used in *Pseudocode*providedinFigure 3.6.

Table 3.1 Symbols and their meanings

Symbols	**Descriptions**
Rs	Residual Energy
Dt	Distance
Rc	Reachability
Φ	Null
RD	Route Discovery
F_Ant( )	Forward_ANT
FLS	Fuzzy Logic System
I & P	Input & linguistic value
FRL	Fuzzy Rule
H & VH	High& Very High
L, VL & M	Low, Very Low & Medium

Table 3.2 Fuzzy Rules

Residual Energy (R_E)	**Distance (D)**	**Reachability (R)**	**Node Selection (Probability)**
Low	High	High	Very Low
Low	High	Medium	Very Low
Low	High	Low	Very Low
Low	Medium	High	Low
Low	Medium	Medium	Low
Low	Medium	Low	Very Low
Low	Low	High	Low
Low	Low	Medium	Low
Low	Low	Low	Very Low
Medium	High	High	Low

Medium	High	Medium	Medium
Medium	High	Low	Medium
Medium	Medium	High	High
Medium	Medium	Medium	Medium
Medium	Medium	Low	Low
Medium	Low	High	High
Medium	Low	Medium	Medium
Medium	Low	Low	Medium
High	High	High	Medium
High	High	Medium	Low
High	High	Low	Low
High	Medium	High	High
High	Medium	Medium	High
High	Medium	Low	Medium
High	Low	High	Very High
High	Low	Medium	Very High
High	Low	Low	High

By applying the ACO technique, the *F_ANT* collects information about all those nodes present in the whole network by multicasting hello messages throughout the network (Table 3.2). The value *(I)*is supplied to the fuzzy logic system (FLS)which in turn generates fuzzy rules *(FRL)* accordingly by using fuzzy inference engine from the fuzzy rule base. It then assignsthe linguistic value *(P)* to the input parameters. Thosevalues are finally compared with the generated output; the comparison helps in choosing the most optimal path from the available ones located in the route along the way towards the destination.

The linguistic values from fuzzy logic systems are:

- ✓ Very Low (VL),
- ✓ Low (L),
- ✓ Medium (M),
- ✓ High (H)
- ✓ Very High (VH).

As we can see in Table 3.2, the totality of 27 rules with the relevant probabilities of a node to be selected based on linguistic values *(P)*isgenerated by the Fuzzy Inference Engine. For example, for a node with a low residual energy but with both high distance to the neighbor node and reachability; the probability that it may be selected as an optimal path is low.Whereas, for a node whose residual energy islow with a high distance but with the medium value of reachability; the probability for getting selected is very low. When a node'sresidual energy and distance aremedium but the reachability value is low,the selection probability value generated is high. The same procedure is followed while generating all the 27 rules.

b) Route Maintenance

During the packet transmission process, the selected paths must keep a high ability to hold the uninterruptible data transfer processes in order to achieve high QoS which minimizes routing delays and packet drop incidents at the same time providing high data delivery ratio. Throughout the routing session, problems arisedue to the mobility nature of participating nodes in the network.The distance between a pair of nodes has a high probability of changing resulting in both an unexpected change oftheir reachability value and an increasedrate of broken links.Hence, a periodic update of the newly available optimal routes iscompulsorywhich are immediately and automatically selected to replace the oneswhich were previously broken, consequently, enabling uninterruptible data transfer.

C) Group Maintenance Phase

The group maintenance phase is the last stageduring which the multicast group is

maintainedin an efficient manner. Due to the mobility nature of MANET nodes, a participating node could easily fall out of its group communication range. To detect such an abnormal event, the source node periodically sends hello messages to the multicast group members, waits for some time period for the reply message from multicast group members. If any group member replies to the hello message, it is immediately considered both as alive and active to be continuously used for communication purposes.Otherwise, the onewhich does not reply to the hello message is automatically considered as dead. The same principle is repeated till the end of the session. The main purpose of the maintenance process is to keep the routing and data transfer processes effective and efficient.

These procedures previously described areapplied in theimplementation processes of the proposed scheme in order to achieve high QoS during multicast transmission of multimedia data in MANET.

3.5. RESULTS AND DISCUSSION

In this section, the proposed approachiscompared with the existing algorithms; ABC (Ant colony Based Cluster) routing, fuzzy integrated ant colony optimization, ACO (Ant Colony Optimization), and Dynamic Core Based Multicast Routing Protocols (DCMP). Through simulation analysis, we provethat the proposed approach providesbest results when compared to the existing ones. The performance evaluation aimsat identifying the optimal paths to route multimedia packets through in order to achieve high QoS in MANET. Those algorithms are briefly discussed below:

1. Ant Colony Based Cluster [ABC]

With ABC technique, cluster formation is achieved using the ACO (Ant Colony Optimization) technique to select the most stable path. A fuzzy logic system isthen utilized to select the appropriate route by generating fuzzy rules with the help of parameters; B_ANT PKTs, mobility, and degree of nodes (Atri et al. (2014)).

2. Ant Colony Optimization [ACO]

Route discovery and maintenance processes arethe two approaches used in order to choose an optimal path.*F_ANT* will forward route request message to the neighbor node and then travels along the network to reach the destination. *B_ANT* also traverses along the same path but in a reverse direction. Based on the collected information such as Delay *(D),* Bandwidth *(B),* and

Hop Count *(HC),* the probability value is calculatedaccordingly. A path with a high probability value is selected as an optimal path. For route maintenance phase, routes are maintained in an efficient manner (Nancharaiah and Mohan (2013)).

3. Fuzzy integrated Ant Colony Optimization [F-ACO]

With this mechanism, fuzzy rules are generated with the help of the following parameters; distance value *(D),* delay *(I),* Capacity *(W),* and power consumption *(P).* F_ANT collectsthis information at each and every node along the way. Based on the probabilistic value, the route isthen selected as an optimal path to route packets through (Nancharaiah and Mohan (2013)).

4. Dynamic Core Based Multicast Routing Protocol [DCMP]

DCMP is an on-demand and mesh-based multicast routing protocol with which more than one source nodes are available. Those nodes are classified as active, core active and passive source nodes. An active source sends the join request message with a control packet at a regular interval of time based on ODMRP routing protocol's rules. A core active source node is also an active source node which plays an important core role for one or more passive sources nodes available in the network. Passive sources are only used for packet forwarding purposes; they work on behalf of the nearby active sources. All those nodes are responsible for creating a shared mesh network. The key concept in this protocol isto make some sources passive which then forwarddata packets through their core nodes. The major advantages of this protocol are its increased scalability, packet delivery ratio, and reduced control overhead (Sandhiya et al. (2015)).

3.5.1 Simulation Model

NS-2 is a discrete event simulator targeted at networking research. It provides substantial support for simulation of routing and multicast protocols over wired and wireless networks. It consists of two simulation tools. It contains all commonly used IP protocols. The network animator (nam) is used to visualize the simulations.

We used two NS-2's key languages: C++ and Object-oriented Tool Command Language (OTcl); while the C++ defines the internal mechanism (i.e., a back-end) of the simulation objects, the OTcl sets up simulation by assembling and configuring the objects as well as scheduling discrete events (i.e., a front-end). After simulation, we output animation-based simulation results. To interpret these results graphically and interactively, NAM and XGraph were used.The result of the simulations is an output trace file that was used to perform data processing (calculate delay, throughput, etc.) using the AWK tool which was also used for data extraction, and reporting.

Table 3.3 Parameter values for simulation

Parameter	**Values**
Number of nodes	50
Interface type	Phy/WirelessPhy
Channel	Wireless Channel
Mac type	Mac/802_11
Queue type	Queue/DropTail/PriQueue
Queue length	201 Packets
Antenna type	Omni Antenna
Propagation type	TwoRayGround
Size of packet	256-1280
Protocol	QAMACF
Traffic	CBR
Simulation area	500M*500M
Node mobility speed	1…20 m/s

As shown in Table 3.3, a network size of 50 nodes is created for performance evaluation. Each node randomly moves with a speed ranging from 1 to 20 m/sec in a simulation area of 500*500M with the transmission range of 250m, the overall simulation time is set to 200 secs. The traffic management operations are performed using Constant Bit Rate (CBR) with the generation rate of 100 kb/s. Each data packet size ranges from 256 to 1280 bytes. IEEE 802.11 for wireless LANs isused at the MAC layer with radio propagation model of Two-Ray Ground. The pause time istaken regularly after 10secs.

3.5.2 Performance Parameter Metrics

The following three metricswere used to compare the performance of theproposed mechanism with the existing ones:

(i) Packet Delivery Ratio (PDR): Itis defined as the ratio of data packets received by the destinations to those generated by the sources. It has to be maintained at the higher level for the overall network lifetime in order to achieve a better network performance.

*PDR= (Received packets/Sent packets) * 100*(3.3)

(ii)Throughput: Itis the amount of data moved successfully from one place to another in a given time period, and typically measured in bits per second (bps), in megabits per second (mbps), or in gigabits per second (gbps). In other words, it is the total number of packets delivered over the total simulation time. For achieving a better performance, it should be maintained high.

Throughput = Received_data/Data transmission period (3.4)

(iii) End-to-end delay: The average end-to-end delay of a data packet is the total amount of transmission delay of packets. It consists of propagation delays, queuing delays, retransmission delays, etc.

End-to-End Delay=∑ (Packet-arrive time – Packet-send time) / ∑ Number of onnections

(3.5)

3.5.3 Comparative Analysis

A performance comparisonis carried outfor theproposed algorithm with the existing ones by varying the routing metrics.

A. Performance Evaluation with PDR

An analysis of the performance of QAMACF against the existing QoS algorithms namely ACO, ABC, and fuzzy integrated ACO is conducted using the Packet Delivery Ratio parameter metric in NS-2.

Table 3.4 PDR of QAMACF and existing approaches varying number of nodes

Number	Packet Delivery Ratio			
of	QAMACF	ABC	ACO	Fuzzy

Nodes				Integration with ACO
10	0.95	0.93	0.9	0.915
20	0.948	0.929	0.897	0.91
30	0.945	0.925	0.895	0.908
40	0.943	0.923	0.892	0.903
50	0.94	0.909	0.888	0.901

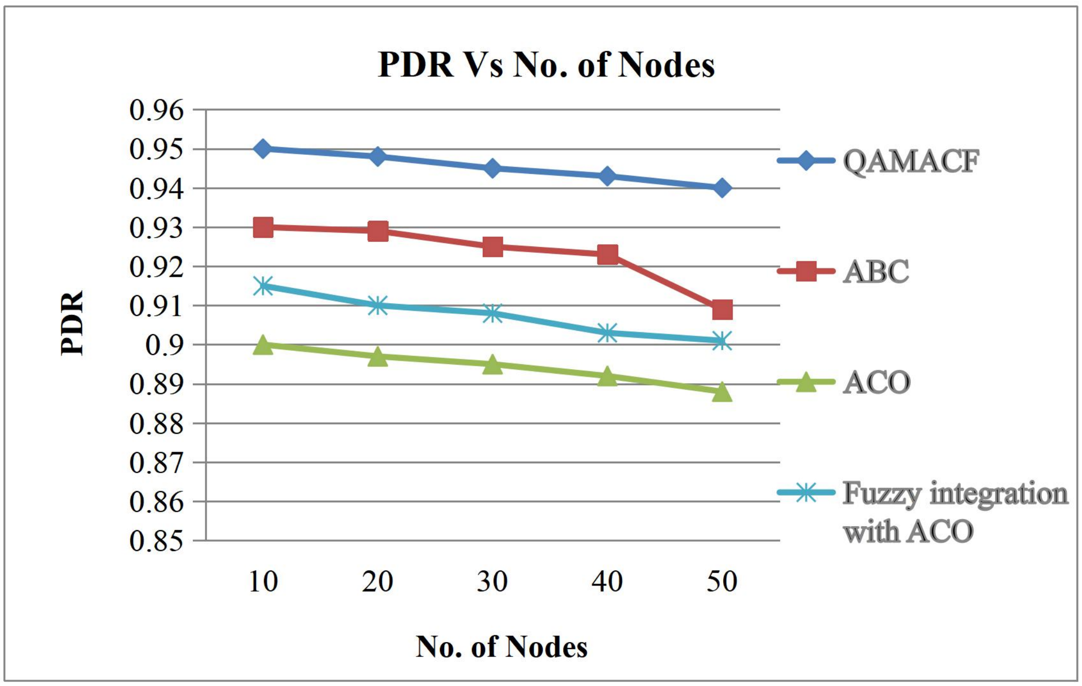


Figure 3.7 PDR vs. No. of Nodes

Table 3.4 and Figure 3.7portray the outcomes of the performance evaluation of PDR with the varying number of nodes. Packet Delivery Ratio of QAMACF remains high for the overall simulation time compared to the other three algorithms'; it is slightly decreased when the number of nodes increases.The same applies to other algorithms due to not having enough capability to handle highly dense networks.

Table 3.5PDR of QAMACF and DCMP varying number of receivers

Number of Receivers (Nodes)	Packet Delivery Ratio

	QAMACF	DCMP
10	0.95	0.935
15	0.953	0.938
20	0.953	0.94
25	0.953	0.945
30	0.953	0.948

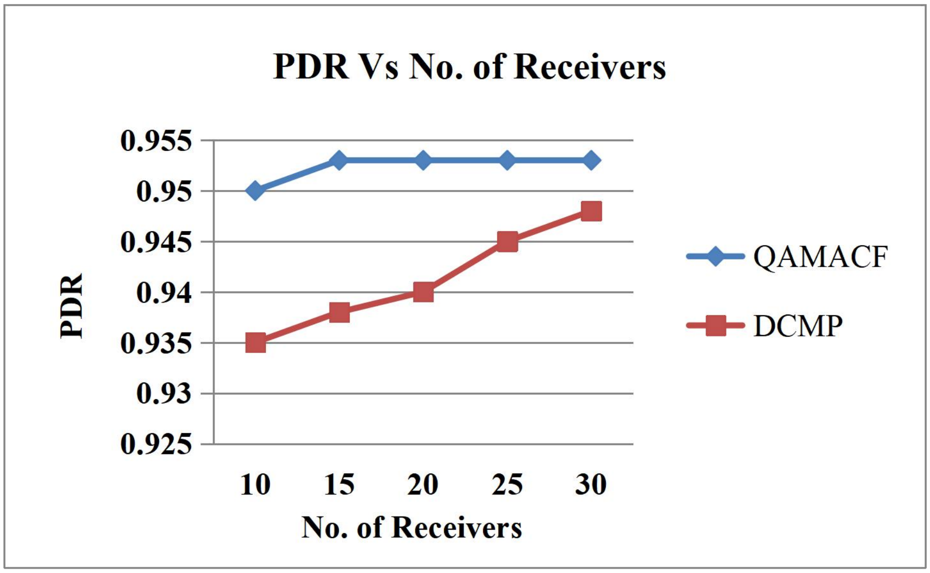


Figure 3.8 PDR vs. No. of Receiver Nodes

As it is seen in Table 3.5 and Figure 3.8, PDR of the proposed algorithm is evaluated against DCMP's. The performance evaluation is conducted considering the number of receivers. During thesimulation process, the number of receivers ranges between 10 and 30 nodes. QAMACF achieves the best results due to its two prominent features; the available high link quality and the capability of selecting a stable path. One interesting observation is that the PDR of both protocols continually increases proportionally to the number of receivers. However, the proposed algorithm, QAMACF keeps a high PDR which DCMP never attains, hence, the outperformance of QAMACF is proved.

B. Performance Evaluation with Delay

It is obvious from Table 3.6 and Figure 3.9 that as long as the end-to-end delay network parameter is concerned about by varying the number of nodes, the proposed algorithm's delay is maintained to the lower level when compared to the existing ones' during the overall simulation time even when the number of nodes is increased, making the proposed protocol a better one. The best performance behavior of the proposed scheme is achieved thanks to the following features; F_ANTpreliminarily collects information regarding the available distance between the source and its neighbor node in combination with its reachability value before starting the path selection process. With the help of the fuzzy logic system, paths that have lower distanceand reachability values are firstly selected as optimal paths and the probability that a data packet will delay reaching the destination is minimized. Another observation remains that all the four algorithms' delays are almost the same when the number of nodes is low (10) and the delays started increasing progressively and proportionally to the number of nodes.

Table 3.6 End-to-End Delay of QAMACF and existing approaches

Number of Nodes	**End to end delay[(secs)]**			
	QAMACF	**ABC**	**ACO**	**Fuzzy Integration with ACO**
10	0.5	1.2	1.5	1.8
20	3	2.5	4.3	3
30	7	8.8	8.8	9.5
40	9	12	12	13
50	12	15	16	16

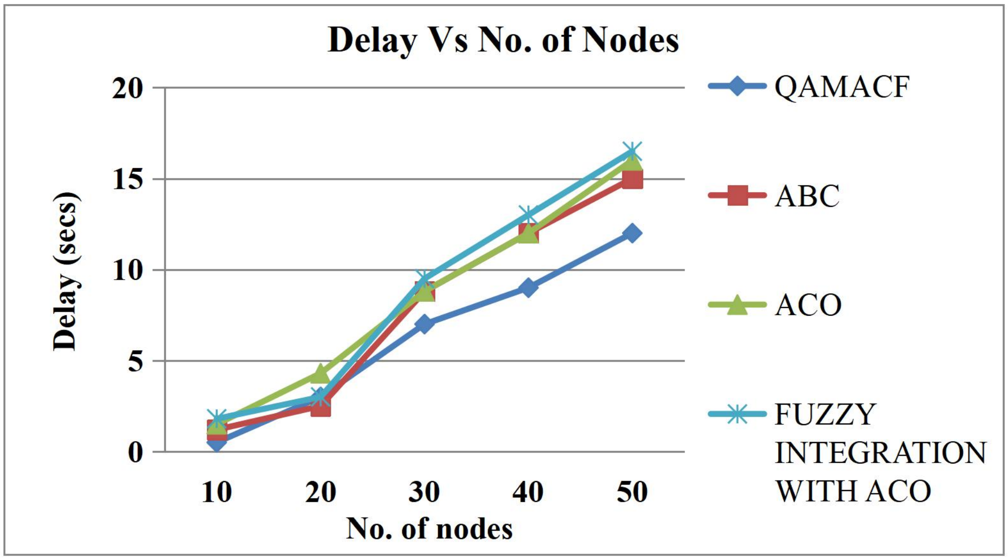


Figure 3.9 End-to-End Delay vs. No. of Nodes

Table 3.7 and Figure 3.10 elucidate the comparative experiments of delay with respect to the varying number of receivers. The proposed protocol is evaluated against DCMP. QAMACF again outperforms DCMP protocol as it maintains a lower level of end-to-end delay ratio for both the low and high number of receivers.

Table 3.7 Delays for QAMACF and DCMP with the varying number of receivers

Number of Receivers (Nodes)	End-to-End Delay[(secs)]	
	DCMP	QAMACF
10	12	11
15	12.6	11.5
20	12.9	11.8
25	13.5	12.2
30	14	12.5

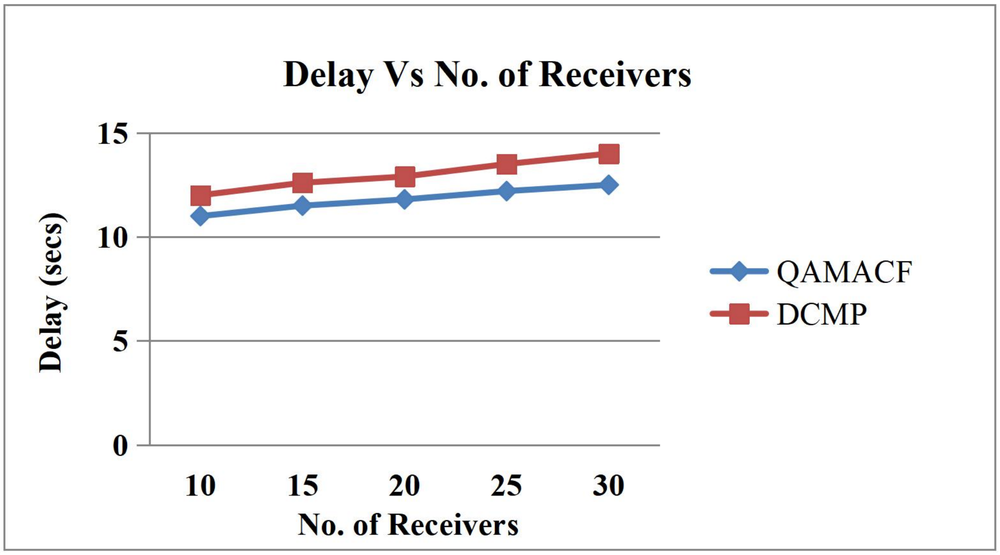


Figure 3.10 End-to-End Delay vs. No. of ReceiverNodes

C. Performance Evaluation with Throughput

In Table 3.8 and Figure 3.11, the performance of the proposed algorithm-QAMACF- in comparison to ACO, ABC, and Fuzzy Integrated ACO techniques is depicted. The results obtained by varying the network size i.e. the number of nodes while considering throughput as an evaluating parameter metricprove that the proposed algorithm attains the maximum ratio of throughput compared to the existing ones.

Table 3.8 Throughputs for QAMACF and existing approaches with the varying number of nodes

Number of Nodes	Throughput [Kb/s]			
	QAMACF	ABC	ACO	Fuzzy Integration with ACO
10	0.96	0.94	0.92	0.925
20	0.958	0.939	0.918	0.922
30	0.955	0.935	0.915	0.92
40	0.951	0.938	0.913	0.928
50	0.95	0.93	0.909	0.91

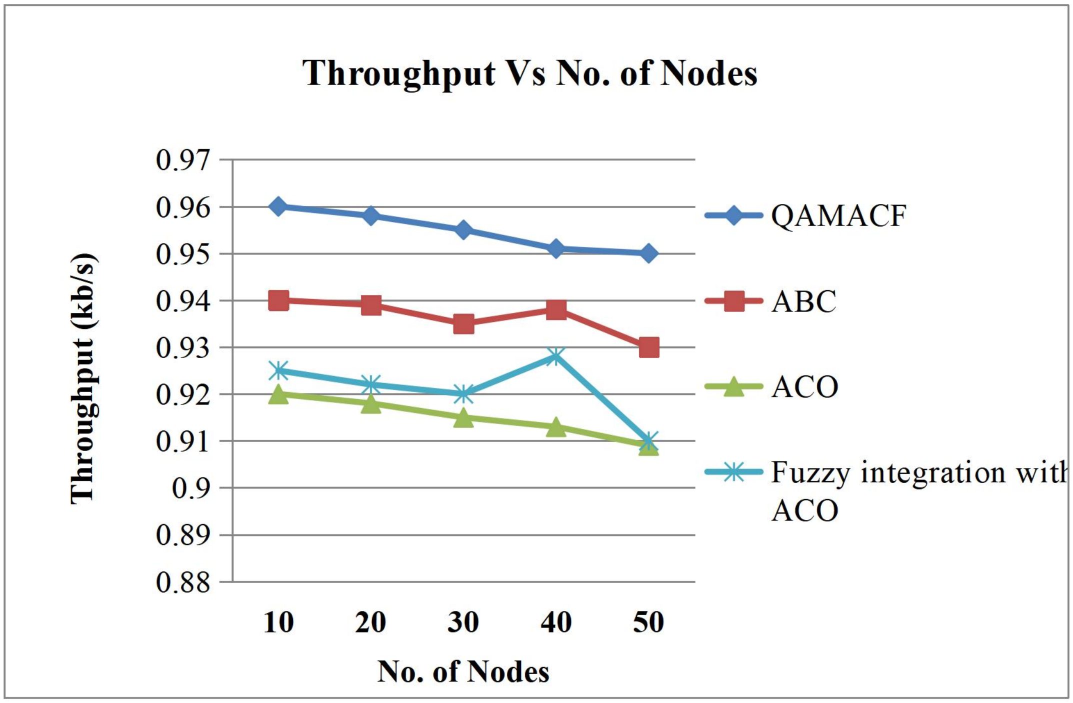


Figure 3.11 Throughput vs. No. of Nodes

Table 3.9 and Figure 3.12 illustrate the effects of the total number of packets received by the source from multiple receivers. The experimentation results show that the throughput values of both the protocols vary starting from high to low when the number of receivers is increased which is due to various receivers simultaneously sharing the same channel. Despite those decreasing values of throughput; QAMACF again outperforms DCMP by keeping higherthroughput values.

Table 3.9 Throughputs of QAMACF and DCMP varying number of receivers

Number of Receivers (Nodes)	Throughput [kb/s]	
	QAMACF	DCMP
10	0.97	0.93
15	0.968	0.927
20	0.965	0.925
25	0.963	0.923
30	0.96	0.921

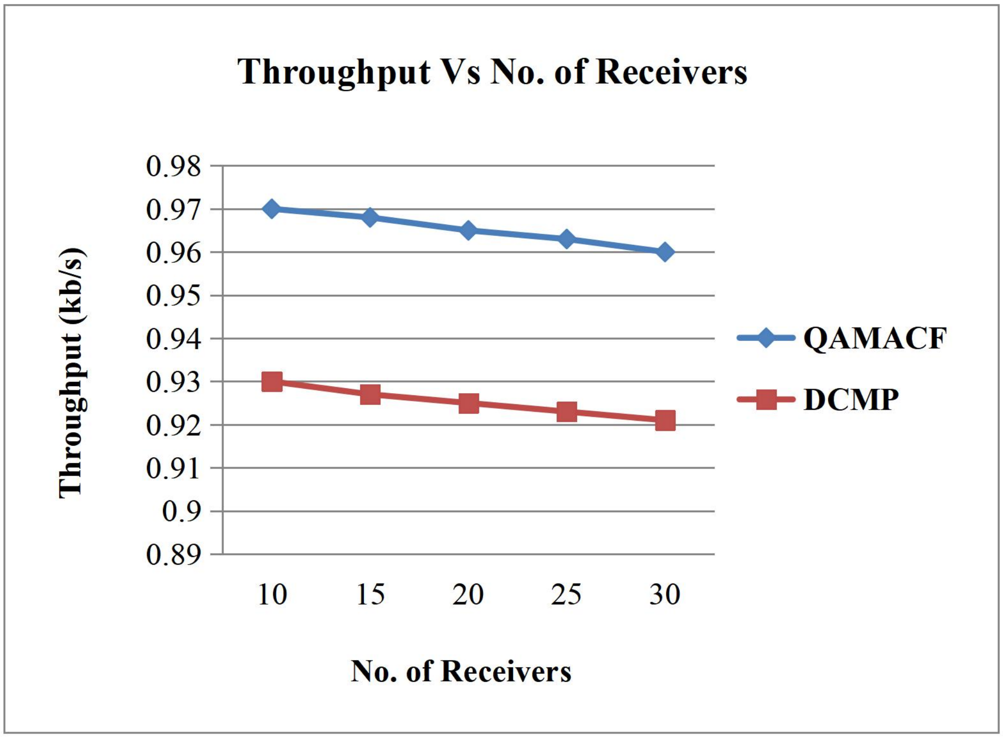


Figure 3.12 Throughput vs. No. of Receiver Nodes

3.6 SUMMARY

MANET is an infrastructureless network;therefore, achieving high QoS is one of its major challenges. Various routing protocols have been designed aiming at providing high QoS in MANET but to date, none of them highly solves problems inhibiting high QoS achievements. To overcome all those negative issues,a new routing algorithm, QAMACF, which is the combination of both ACO and fuzzy logic mechanisms has been proposed. It also took into consideration two prominent features in MANET; multicast and multimedia transmission techniques. For performance evaluations, three different parameter metrics namelyDistance (Dt), Residual energy (Re), and Reachability (Rc) were used. Those parameters were accumulated by F_ANT used in ACO at each node by forwarding hello messages. The collected information was supplied as inputsto the fuzzy logic systemwhich then generated a combination of 27 different fuzzy rules based on the input parameters provided from the fuzzy rule base available from the Fuzzy Inference System (FIS).FIS finally calculated the probabilistic value determining whether a given node present in the network could be selected as an optimal path. Upon finding an optimal route to transmit packets through, the packet transmission process then started followed by themaintenance of the selected routes. The experiments were evaluated using the NS-2 simulator which comparedthe proposed algorithm (QAMACF) with the existing ones namelyABC, ACO, Fuzzy integration with ACO,and Dynamic Core Based Multicast Routing Protocols (DCMP). Different scenarios were studied applying various prominent routing metrics such asPDR, End-to-End Delay, and throughput by alternatively varying the number of nodes and receivers. Theproposed algorithm outperformed the existing ones inall the studied cases; this achievement was possible owingto the combination of multiple prominent techniques used in the protocol's implementation. Thealgorithm proved to beefficient in transmitting both ordinal and multimedia data packets even in highly dynamic MANETs as opposed to the existing ones.

CHAPTER 4

QoS-BASED ROUTING APPROACH USING GENETIC ALGORITHMS FOR REAL-TIME MULTIMEDIA APPLICATIONS

Genetic Algorithm (GA) is an adaptive heuristic search algorithm based on the evolutionary ideas of natural selection and genetics. As such, they represent an intelligent exploitation of a random search used to solve optimization problems. Although randomized, GAs are by no means random, instead, they exploit historical information to direct the search into the region of better performance within the search space. The basic techniques of the GAs are designed to simulate processes in natural systems necessary for evolution. In nature, competition among individuals for scanty resources results in the fittest individuals dominating over the weaker ones.

GeneticAlgorithm is a problem solver tool to resolve the NP-complete problem which has beengenerally used to solve the complex issues in various fields by researchers.Four different steps are followed during the resolving process namelyinput selection, fitness function calculation, mutation, and the crossover technique and finally, the output is generated based on the iterations provided. For example, Tamer (2006) used this technique to identify the optimum path between the source and destination nodes even in the presence of multiple constraints. Upon the successful completion of the path selection process, the packet scheduling algorithm was used to reduce the unwanted packet dropping ratio and minimize the network traffic-related problems.

Those two mechanisms were very effective in increasing the QoS ratio in highly dynamic networks with speedy nodes. The Genetic Algorithm was also used by (Prasanna et al. (2014); Yen et al.(2008); Sun et al.(2008); Gaur (2013); Haghighat et al.(2002); Huang andLiu (2010)). It aimedat providing a high QoS in MANETs by considering the power constraints as the main issue.

(Basarkod and Manvi (2014); Sutariya and Kamboj (2013)) implemented various QoS routing protocols for MANET.Each routing mechanismconcentrated only on optimum path selection either after its identification or during the packet transfer process where packet overflow could unpredictably occur. All those researches confirmed that multimedia data transmission processes usually consume a huge amount of energy causingsome nodes to be unexpectedly shutdownwhich further produces a higher transmission delay and a lower throughput.

4.1. MULTIMEDIA TRANSMISSION OVER MOBILE AD HOC NETWORKS

Multimedia packets refer to the data or information being transmitted over the network and can be of the following types: audio, video, text, images, photo, animation, and interactive content. Multimedia is classified into two categories i.e. linear and nonlinear. Linear active information (data content) progresses without the need of any navigation control for the viewer, a cinema presentation is an example of such data. Nonlinear information or data such asvideo games require user interaction and navigation control. Hypermedia, an extension of the term hypertext, is a nonlinear medium of informationwhich includes graphics, audio, video, plain text, and hyperlinks. This contrasts with the broader term multimediawhich may include non-interactive linear presentations as well as hypermedia.

Transmitting multimedia information from one end to another poses various challenges and requires efficient techniques such as multicast which is a mechanism to discover and maintain routing paths, real-time applications efficient in achieving a successful transmission of either ordinal or multimedia data. Due to the complexity of this scheme, there is always a very high demand for Quality of Services (QoS). Various algorithms have been proposed by various researchers in this field targeting at enhancing the Quality of Service by taking into account multiple QoS constraints but none of them provides an efficient mechanism for this achievement. Two techniques, combined together have been proved by various researchers to be very successful in providing a high QoS during the multimedia data transmission namely the Genetic Algorithms and Dynamic Priority Packet Scheduling techniques.Hence, the same approaches have been adopted in this work.

4.2 GENETIC ALGORITHMS WITH DYNAMIC PACKET SCHEDULING

4.2.1 Genetic Algorithm

An evolutionary algorithm is a term used for solving computer-based problemswhich use computational models of evolutionary processes as key elements in their design and implementation. Various evolutionary algorithms have been proposed. The major algorithms are listed below:

- Genetic algorithms
- Evolutionary programming
- Evolution strategies
- Classifier system
- Genetic programming, etc.

A genetic algorithm is the most popular algorithm among other evolutional algorithms; it is an adaptive searching and meta-heuristic computational method inspired by biological evolution. It is used in various fields such asthe aircraft industry, chipdesign, telecommunications, software creation, computer animation, drug design, and financial marketing. In general, genetic algorithms are different from other heuristic methods. Major differences between genetic algorithms with the other methods are:

- The most important difference is that a GA works on a population of possible solutionswhile other heuristic methods use a single solution in their iterations.
- A genetic algorithm is stochastic, not deterministic. Each individual in the genetic algorithm population represents a possible solution. Some individuals are selected based on the fitness value. Then, the genetic algorithm imitates the natural genetic process, crossover, to exchange some of these individual genetic data randomly to generate the offspring (Singh andYadav (2015)).
- Furthermore,
    - Genetic algorithms work with a coding of the solution set, not the solutions themselves.
    - Genetic algorithms search from a population of solutions, not a single solution.
    - Genetic algorithms use payoff information (fitness function), not derivatives or other auxiliary knowledge.
    - Genetic algorithms use probabilistic transition rules, not deterministic rules.

Begin

G: =0;

Initialize P (G); {P (G) is the population of P_{Dim} individuals in generation G}

While (no termination condition) do

Begin

Evaluate P (G);

Select best P (G); {P_{best} (G) is the most fitting part of P(G) }

Discard worst P (G); {P_{Worst} (G) = P(G) – P_{best}(G) }

Crossover P_{best} (G); {P_{cr} (G) is the crossover of P_{best} (G)}

Mutation P_{cr} (G); {P_{mut} (G) is the mutation of P_{best} (G)}

P (G) = P_{best}(G)+ P_{mut}(G); {P_{dim} does not change because |P_{mut}(G)|=|P_{worst}(G)|}

G=G+1;

End

Figure 4.1 Genetic Algorithm implementation

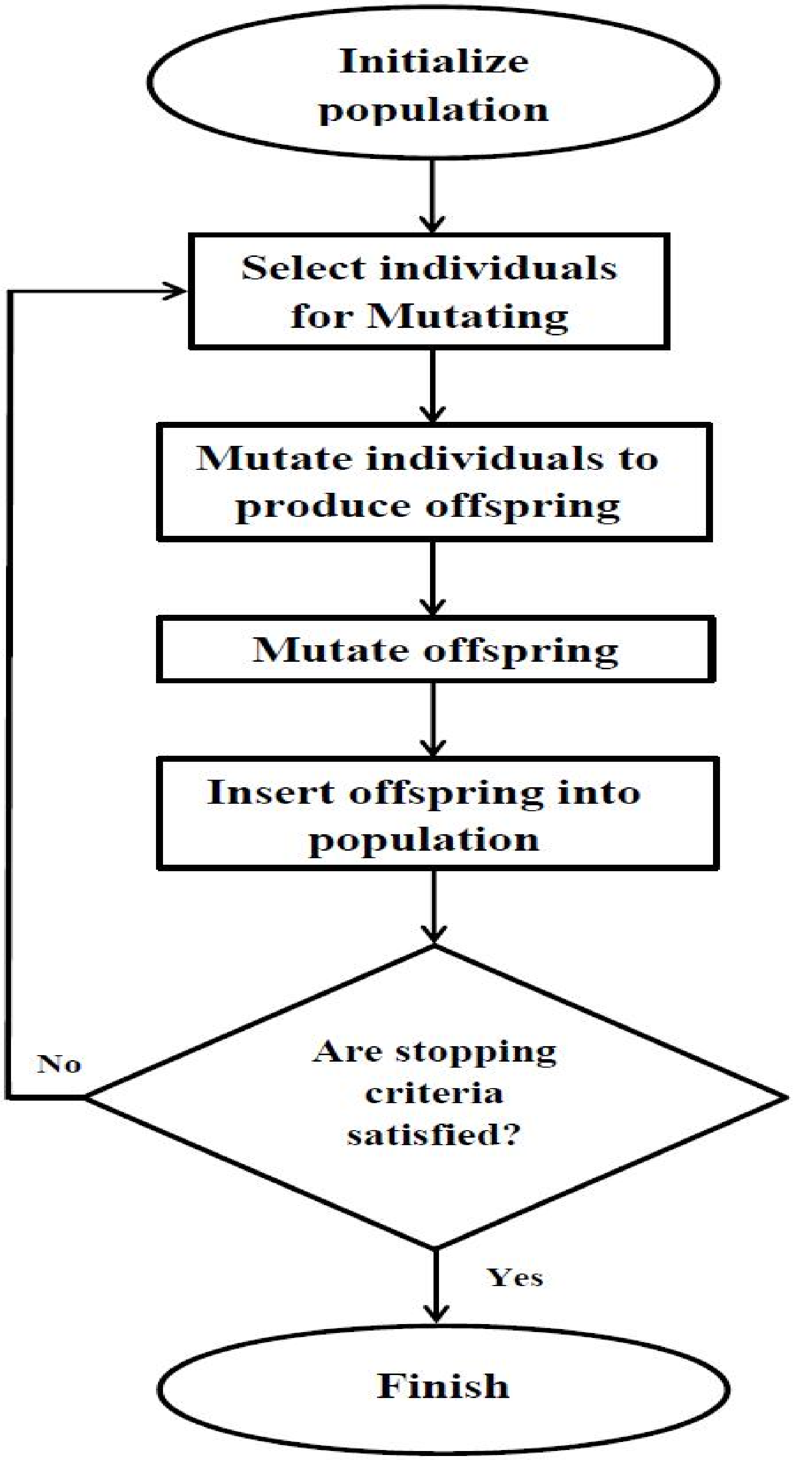


Figure 4.2 Genetic Algorithm working process

4.2.2. Motivations for Using Genetic Algorithms

• *Generality and Versatility:* GAs apply in a wide variety of settings and can be easily molded to particular problems, thus,capable of solving extremely large problems that have large search spaces.

• *Adaptiveness and Online Problem Solving:* GAs canachieve near-optimal exploration and exploitation tradeoff. They are well suited for building metaheuristic adaptive algorithms that can provide satisfactory performance in changing network conditions. Another important issue is that GAs are online adaptive algorithms that can operate in unknown environments in an online fashion.

• *Ability to Find Good Building Blocks*: By working in terms of a population of candidate solutions, genetic algorithms can exploit the diversity of solutions to find building blocks known as schemas in the literaturewhich are substrings of chromosomes that denote high performing elements of the overall solution.

• *Parallel Nature and Scalability:* Traditional theory of GAs presumes that they accomplish the culmination by discovering, emphasizing, and recombining the good traits of chromosomes in a vastly parallel manner.

• *Support for Multi-objective Optimization:* Many practical problems in wireless networks require optimization ofmultiple parameters (that may potentially conflict with each other). An important characteristic of a GA is that it can easily support joint optimization of multiple objectives.

• *Support for Global Optimization:* Unlike network models such as the multi-layered perceptron, GAs are suited to findthe global optima due to a number of properties as they search by means of a population of individuals. They work with an encoding of multiple parameters. They use a fitness function that does not require the calculation of derivativesandthey search probabilistically.

• *Easy Implementation:* GAs are computationally simpler compared to other complementary AI techniques such asneural networks since they require only swapping and shifting of genes in chromosomes (unlike neural networks that require adders for their multiple hidden layers).

4.2.3 Elements of genetic algorithm

Genetic algorithms encode the decision variables of a search problem into finite-length strings of alphabets of certain cardinality. These strings are referred to as *chromosomes*which are represented by a candidate solution. The *string* is represented as a characterwhich denotes*genes.* Gene position and the corresponding value are known as*locus* and *allele*.

A *fitness function* sometimes called the objective function, offers a mechanism for the evaluation of the individual chromosomes. A *population* of candidate solutions (called individuals, creatures, or phenotypes) to an optimization problem is evolved towards better solutions. Each candidate solution has a set of properties (its chromosomes or genotype) which can be mutated and altered; traditionally, solutions are represented in binary as strings of 0s and 1sthoughother encodings are also possible. The *initial population* is randomly created only after the clear knowledge of a particular problem. Individuals are evaluated using a fitness function. New offsprings are then generated by applying crossover and mutation operators on the parents (Singh andVirk (2013)).

Chromosomes:

The most important and necessary step in applying a genetic algorithm to a problem is to choose a way to represent a solution to the problem as a finite length of string or chromosome. They may represent Boolean value, binary digits, integers, or even discrete real numbers.

Fitness function:

The fitness function is simply defined as a function which takes a candidate solution to the problem as input and produces as output how “fit” or how “good” the solution is with respect to the problem in consideration.

Genetic operators:

These alter the genetic composition of the offspring. These include crossover, mutation, selection, etc.

Initial population:

There are two primary methods to initialize a population in a GA. They are:

- *Random Initialization:* Populate the initial population with completely random solutions.
- *Heuristic initialization:* Populate the initial population using a known heuristic for the problem.

It has been observed that the entire population should not be initialized using a heuristic, as it can result in the population having similar solutions and very little diversity. It has been experimentally discovered that the random solutions are the ones to drive the population to optimality. Therefore, with heuristic initialization, the population will be just seeded with a couple of good solutions, filling up the rest with random solutions rather than filling the entire population with heuristic-based solutions. It has also been observed that heuristic initialization in some cases, affects only the initial fitness of the population, but in the end, it is the diversity of the solutionswhich leads to optimality.

4.2.4 Working Principle of Genetic Algorithms (GAs)

Algorithmically, the basic Genetic Algorithm (GA) is outlined as below (Vankudoth et al. (2016)):

Step I [Start]: Generate random population of chromosomes, that is, suitable solutions forthe problem.

Step II [Fitness]: Evaluate the fitness of each chromosome in the population.

Step III [New population]: Create a new population by repeating the following stepsuntilthe new population is complete.

a) [Selection]: Select two parent chromosomes from a population according to their fitness. Better the fitness, the bigger is the chance to be selected.

*b) [Crossover]:*With a crossover probability, crossover the parents to form a new offspring, i.e. children. If no crossover is performed, offspring is the exact copy of parents.

c) [Mutation]: With a mutation probability, mutate new offspring at each locus.

d) [Accepting]: Place new offspring in the new population.

Step IV [Replace]: Use the newly generated population for a further run of the algorithm.

Step V [Test]: If the end condition is satisfied, stop, and return the best solution in the current population.

Step VI [Loop]: Go to step II.

4.2.5 Dynamic Priority Scheduling Techniques -

Dynamic Priority Packet Scheduler with Deadline Considerations and Static Priority Packet Scheduler with Deadline Considerations

DPD and SPD integrate an important QoS parameter (the delay) into the classical static priority packet scheduling algorithm and analyse the packet losses by considering the two different components of losses; buffer overflows and deadline violations. These schemes not only reduce the complexity of the static priority algorithm by introducing the degree of sorting but also solve the starving problem and provide fairness to applications with different priorities. The important concept of this algorithm is how to determine the threshold levels for changing priorities of the packets. The two sets of algorithms introduced; Static Priority with Deadline considerations (SPD) and Dynamic Priority with Deadline considerations (DPD) not only simplify the complexity and overhead of a classical Earliest Deadline First (EDF) or Static Priority (SP) algorithm but also provide a better QoS based on results of the evaluation conducted(Tamer(2006)).

4.3PROBLEM DESCRIPTION

4.3.1 Energy Consumption with Packet Forwarding

Packet transmission processes between various nodes in MANET consume some amount of energy. Lu and Zhu (2013) and Tamer (2006) discussed some useful algorithmswhich are efficient in managing the power consumed by the network traffic in order to provide a high QoS in MANETs. To achieve this, a lower energy consumption is required for a link between two different nodes v_i, v_j during a unit transmission of the message which is defined as follows,

$$P_{i,j} = y_1(r_{i,j})^{\beta} + y_2 \quad (4.1)$$

Where$r_{i,j}$ is the Euclidean distance between v_i and v_j, $y_1$is a constant dependent on the properties of the antenna, β is a path loss exponentwhose value depends on the propagation losses in the medium, and y_2 is a constant used to represent the overheads incurred during electronics and digital processing operations. It isassumed that during the multicasting processes, only a unit message is transferred. To reduce the packet overflow, MDPD-k scheduling algorithmwhich is efficient in handling the packet scheduling operations in an effective manner is used.

4.4 METHODOLOGY

4.4.1 Analytical Model for the Proposed Network Representation

In theproposed work, it is presumed that every node in the network calculates the distance between itself and its neighbor nodes by using the distance calculation method (Lu and Zhu (2013)). The network connectivity is shaped in bus topology with a backbone connecting all nodes, each one having its own transmission powerwhich can be dynamically changed. For example, for each multicast tree, the transmission power level of each participating node $v_i$ischanged based upon each node's participation. An omnidirectional antenna is used for each node (v_i),where two coverage areas areavailable for each node present in the network namelyControl Coverage area (CR_i) and Data Coverage area (DR_i), where$DR_i \subseteq CR_i$.

Depending upon both the transmission power required for transmitting data and the number of control packets for each node (v_i), the coverage area for various nodes will differ. This network model can be represented in the form of a graph $G(V,E)$ which depends on the control coverage area of each participating node, where$V$ isa finite set of vertices (the number of nodes or mobile devices), hence, $V = \{v_1, v_2, \ldots, v_n\}$ isa set of nodes, and $E = \{(i,j)|v_i, v_j \in V\}$ *is* a set of links, $(i,j) \in E$denotesthat both v_i and v_j are within the coverage area of each other. Each link status isdependent on the values of the delay $(d_{i,j})$, distance $(l_{i,j})$, and bandwidth $(b_{i,j})$ parameters.

Data transmission delay between nodes v_i and v_j is denoted by $(l_{i,j} \,.\, d_{i,j})$, this includesboth the queuing and propagation delays. Euclidean distance between nodes $v_i$and $v_j$is denoted by $(l_{i,j})$ and the bandwidth of the link between v_i and v_j is denoted as $(b_{i,j})$. The $(d_{i,j})$, $(l_{i,j})$,and $(b_{i,j})$ are all positive real numbers. The multicast source $(s \in V)$ and multiple destinations $(D \subseteq V - \{s\})$ are considered.$d = |D|$is the number of multicast destination nodes in a multicast tree. $M$is a destination group and $\{s\}\ U\ D$isthe multicast group.

A multicast tree denoted as $T(s,D) \subseteq G$s is a tree having a root from a single source to all the destinations in D. A delay occurred during a data transmitted along a path from source (s) to the destination nodes participating in a *tree* (T), $(v_t \in D)$ isdenoted as $delay\ (p_T(s,v_t))$, where$(p_T(s,v_t))$ is a unique path from s to $(v_t \in D)$.

$$Delay\ (p_T(s,v_t)) = \Sigma_{(i,j) \in p_{T(s,vt)}}\, d_{i,j} \quad (4.2)$$

The minimum bandwidth of a path from source s to the destination $(v_t \in D)$ is denoted as bandwidth $(p_T(s,v_t))$.

$$bandwidth\ (p_T(s,v_t)) = min\{b_{i,j}\ ,\ (i,j) \in p_T(s,v_t)\ \} \qquad (4.3)$$

Δ_d is the delay constraint and B_d is the bandwidth constraint of the destination node $(v_t \in D)$. Then, the delay-bandwidth constraint minimum Steiner tree problem to find theminimum cost multicast tree $T^*\ (s,D)$ is,

$$delay\ (p_T^*(s,v_t)) \leq \Delta_d,\ \ \forall v_t \in D \qquad (4.4)$$
$$bandwidth\ (p_T^*(s,v_t)) \geq B_d,\ \ \forall v_t \in D \qquad (4.5)$$

Once $T^*\ (s,D)$ is identified during data packets transmission in tree T^*,each node will itself adjust its transmission power level.

4.4.2 Proposed Algorithm

In this research work, a new protocol, GDAQM (Genetic with DPD for Attaining QoS in MANET) has been proposed. It combines both the Genetic and Modified DPD-k (Dynamic Priority with Deadline Considerations). Three different parameters namely delay, bandwidth, and cost during the route selection processare considered. Thereafter, for packet scheduling, MDPD-k (Modified DPD-k) scheduling algorithm is usedwhich avoidsboth the packet and traffic overflows and increases the Quality of Service of the network. Generally, the genetic algorithm has the following steps: coding, initial population, fitness function evaluation, selection, mutation, crossover, and analysis of convergence. Pseudocode 1 provides a detailed explanation of theproposed genetic algorithmwhichselects energy-efficient, least-cost, maximum-bandwidth, multi-constraint QoS path in which *RandomDFS()* represents the random depth-first search algorithm, N_g isthe number of generations and $N_{optimal}$denotes the number of best individuals present in solution. Three different parameters namelydelay, bandwidth, and cost areused during the overall route selection process. The MDPD-k scheduling algorithm isthen used to avoid packet and traffic overflow events which further increases the QoS (Quality of Service) of the network.

Figure 4.3 exhibits an overview of the proposed GDAQM routing mechanism which is a multicast routing protocolwhere multiple destination nodes are involved.

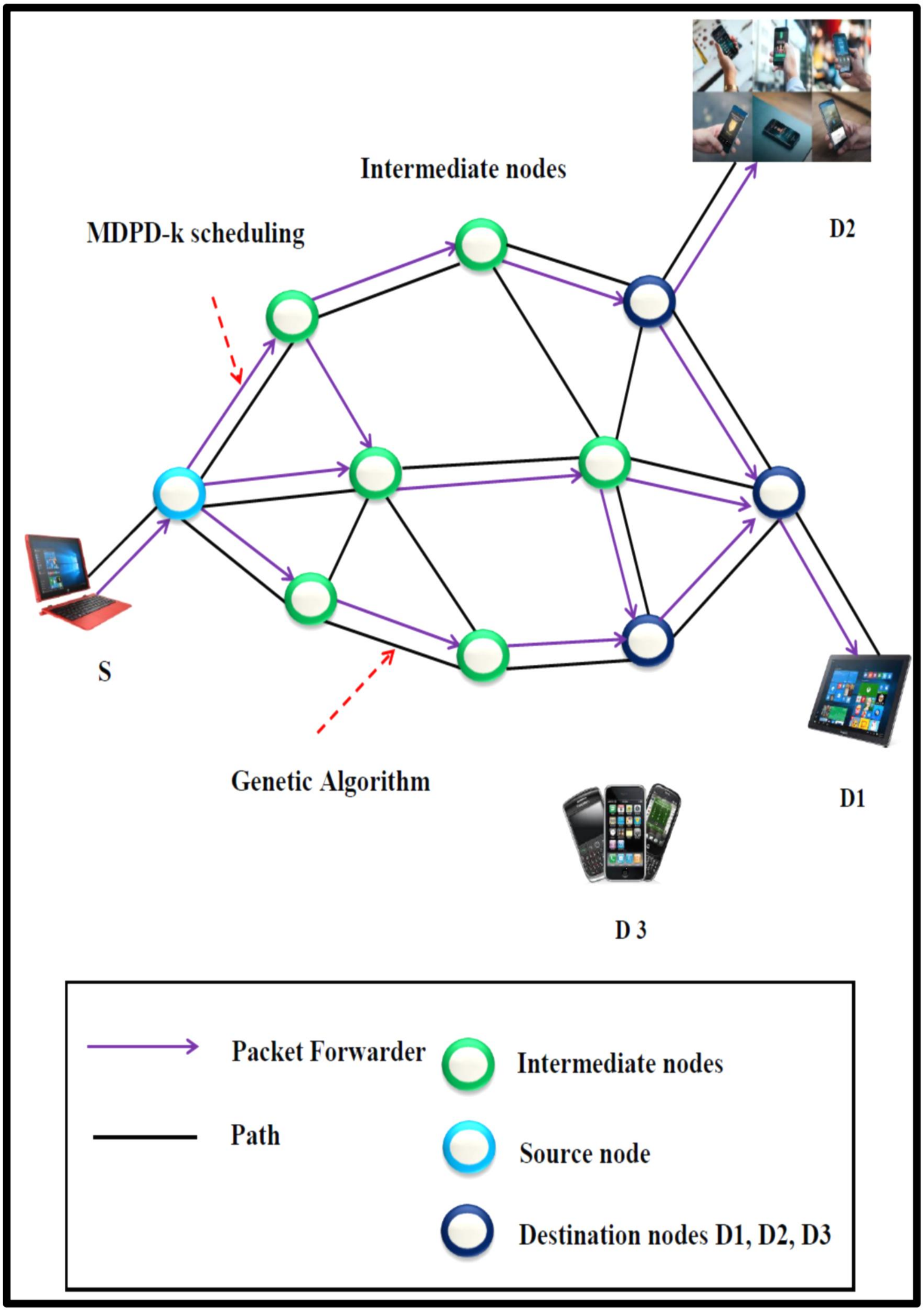


Figure 4.3 Overview of GDAQM architecture

Genetic Algorithm

Coding

To design a well-represented Genetic Algorithm, a suitable solution to candidate individual representation is very much required as it plays a major role in genetics.

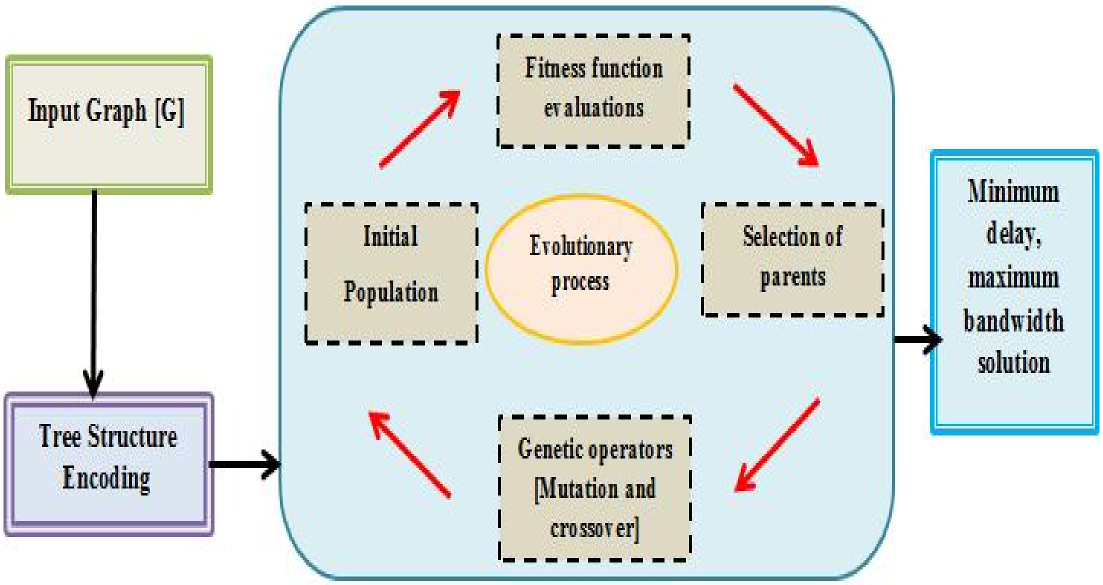


Figure 4.4 Architecture of Genetic Algorithm

Various representations of a tree such asone-dimensional binary code, sequence, and topology encoding (ST encoding) presented by Lu and Zhu (2013) and Prüfer number discussed byHaghighat et al. (2002)have been introduced by different previous researchers. One main problem with this representation was that they generated illegal trees, might have poor locality, or a low efficiencywhich always further results in the remarkable augmentation of the required search space as the network size increases.

To excludeall those negative issues, some researchers working onthe network optimization technique-related issues have introduced a new scheme with which they directly manipulated trees i.e., using a data structure of a tree to describe the chromosome (Lu and Zhu (2013)). In this method, a tree directly representsa chromosome. Therefore, the coding/decoding operations were omitted. In this study, the tree structure coding methodis usedin which a chromosome represents a multicast tree directly. Figure 4.4 exhibits the overall working process of the genetic algorithm.

Initial population

The initial population process is the foundation of the genetic algorithm; a new generation is created by using the reproduction mechanism. The population size *(N_p)* and the method of population formation are the two important issues taken into consideration during this prominent stage. In the proposed algorithm, the initial population is generated based on the random depth-first search algorithmwhere the searching process begins at *s* and randomly selectsthe unvisited node to be next visited. The iterationloops until the end of the process i.e. when all the individuals have been visited (Ravikumar and Bajpai (1998)).

Fitness Function

Upon completing the initial population formation process, the next step is to select individuals according to their performance. A node's performance is estimated by calculating the efficiency of each individual using the evaluation parameters, for example, delay, bandwidth, and cost in the currentcase. "Good individuals" have a bigger fitness compared to the "bad ones"which is the job of the fitness function asdefined by the following mathematical expression:

$$f(T) = \left\{\frac{a}{cost(T)} \prod_{v_t \in D} \varphi\big(delay\big(p_t(s, v_t)\big) - \Delta_d\big) \prod_{v_t \in D} \varphi\big(bandwidth\big(p_t(s, v_t)\big) - B_d\big)\right\} \quad (4.6)$$

where

$$cost(T) = \sum_{v_i \in T} c_i^T = \sum_{v_i \in T} b[y_1 \left(r_i'\right)^{\beta} + y_2] \quad (4.7)$$

and

$$\varphi(Z) = \begin{cases} 1, if\ Z \le 0, \\ \gamma,\ \ if\ Z > 0 \end{cases} (4.8)$$

In the *equation* (4.8),*a* is the positive real weighting coefficient, *δ,* the maximum allowable delay from *s* to *vt*where *vt* ∈*D*. *cost(T)* is the energy cost of tree *T. Φ(.)* is a penalty function. The value *γ(0 < γ <1)* determinesthe degree of penalty; the smaller the value of *γ*, the higher the degree of penalty. In the present study, *γ = 0.5.*

The energy consumption of a multicast treeis reduced to maximize the network service time. In equation (4.7),c^T_i is the energy cost of *vi*, *b* isa positive real coefficient, and *r_ i,*isthe maximum distance between *vi* and *vj*where *vj* ∈ *B*(*vi*). *B*(*vi*) is the set of immediate succeeding nodes of *vi* on *T*. The energy cost of leaf nodes is zero. Particularly, $k1 = 1$, $k2 = 0$, $b = 1$, and $\beta = 2$are setsin the proposed study.

Selection of Parents

When selecting parent individuals, a suitable elitist model is used.The process isperformed as follows: the best individualsare first selected, and then copiedinto the next generation, and the rest of the individualsare selected using the roulette wheel selection model. The probability of selecting a given parent, for example, *Ti*, denoted as *p (Ri),* is given by:

$$p(R_i) = \frac{f(T_i)}{\sum_{j=1}^{N_p} f(T_i)} \quad (4.9)$$

Where $f(T_i)$ represents the fitness of the individual, *Np* is the population size.

Crossover Scheme

Crossover, also known as recombination is a genetic operator used to vary the programming of a chromosome or different chromosomes from one generation to the next one. In networking, this technique is specially used to find out an optimal route to transmit packets through. A single offspring is produced througha pair of chromosomes selected as the parents based on the roulette wheel. *Ta*and *Tb* areconsideredas the twoselectedparentsrespectively. The crossover operator generates a new child *Tc* while identifying the same links between *Ta* and *Tb*but retaining these common links in *Tc.*The common links between the two parents would represent the "good traits" as according to the fitness functionwhich states that the "better individuals have a very high probability to be selected as parents".However, those common links in *Tc* might generate subtrees as theyareretained and various links are required to connect these sub-trees into a multicast tree **(**Aggarwal et al. (2014)).

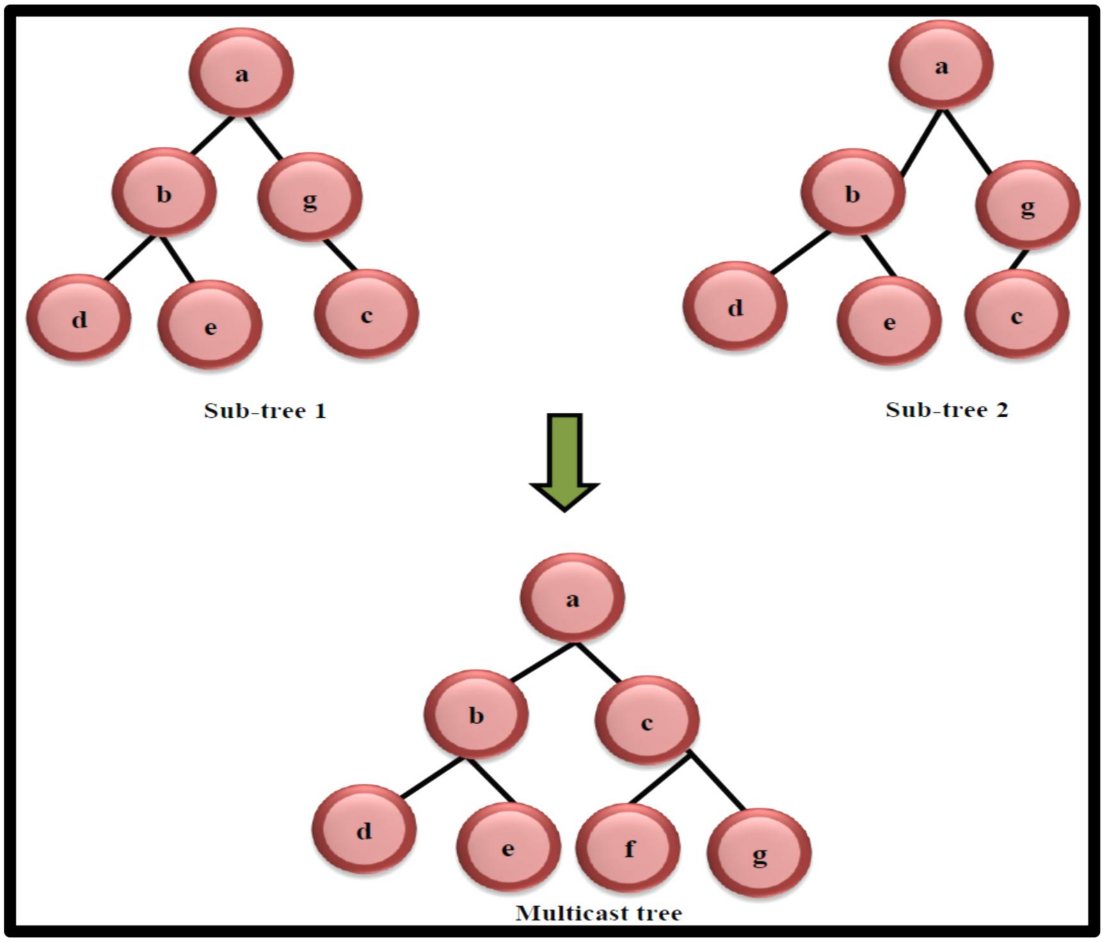


Figure 4.5 Crossover operation

In order to connect those sub-trees, the following processes are followed: first of all, two separate sub-treesare randomly selected among the others. Then, a new sub-tree is formed by those selected ones linked by a least-delay path. The connection loop continues until a multicast tree is fully constructed. Two nodes areadded in order to find the least-delay path between those two sub-trees. One node is connected to all the nodes of one sub-tree with linkswhich have zero-delay associated with them. Similarly, the other nodesareconnected to all the nodes of the other subtree with zero-delay links. Hence, the least-delay path between the two sub-trees is the least-delay path between the two added nodes. The connection scheme is very effective as it avoids routing loops in the multicast tree, as shown in Figure 4.5.

Mutation

Upon completing the offspring production operations, the mutation stage begins according to the mutation probability,p_m.The mutation procedure randomly selectsa subset of nodes and some separate sub-trees arebroken from the multicast tree by removing all the links that connect those selected nodes and their farthest child node on *T.* Those separate sub-trees arereconnected into a new multicast tree with the least-delay paths. Then, a new multicast tree is generated by connecting the two sub-trees using a powerful mutation operator **(**Aggarwal et al. (2014)).

Analysis of Convergence

The proposed genetic algorithm focuses on the global optimal solution based on the theorem discussed by Hussein and Al-Salih (2014). It is a time-consuming task to find out an optimal solution to the NP-complete problems when considering large-scale networks. By setting the suitable iteration time for the genetic algorithm, we overcome those negative issues. Hence, in implementing the proposed genetic algorithm, the methodology described by Lu and Zhu (2013) is used, thereby, obtaining a near-optimal solution within a reasonable time limit.

Figure 4.6 shows the pseudocode of the proposed genetic algorithm. *RandomDFS*() function denotesrandom depth-first search algorithm, *Ng* is the number of generations, *N optimal* isthe number of the best individuals:

```
GeneticAlgorithm(G, s, D){
  For(i=1; i<=Np; i++) {
    Chromosome(i) = RandomDFS(G, s, D)
}
  For(j=1;j<=Ng; j++){
    Choose best individuals and copy them into the next generation
  For(k=1;k<=Np-Noptimal; k++) {
     Ra=MSTSelect(Chromosome)
     Rb=MSTSelect(Chromosome)
     Rc=Crossover(Ra, Rb)
     If(rand()<pm)
       Mutation(Rc)
}
}
Choose the best individual and output it
}
```

Figure 4.6 Individual Selection using Genetic Algorithm

MDPD-K Packet scheduling scheme

Upon completing the path selection process, for forwarding data during the multicast transmission, MDPD-k packet scheduling algorithm is used. Generally, for achieving successful packet scheduling processes, any one of the parameters such as the deadline or priority was used by various researchers but without success. Tamer (2006) combined both of them. In this study, a different approach is followed to achieve the same operation using the slack time. Packets arescheduled at each node using Least Slack First (LSF) scheduling algorithm in order to achieve fairness in the packet scheduling for the soft-deadline driven application so as to achievesuccessful forwarding. A packet's slack time is calculated by using the following formula:

$$S_t = D_p\text{-}t\text{-}c' \quad (4.10)$$

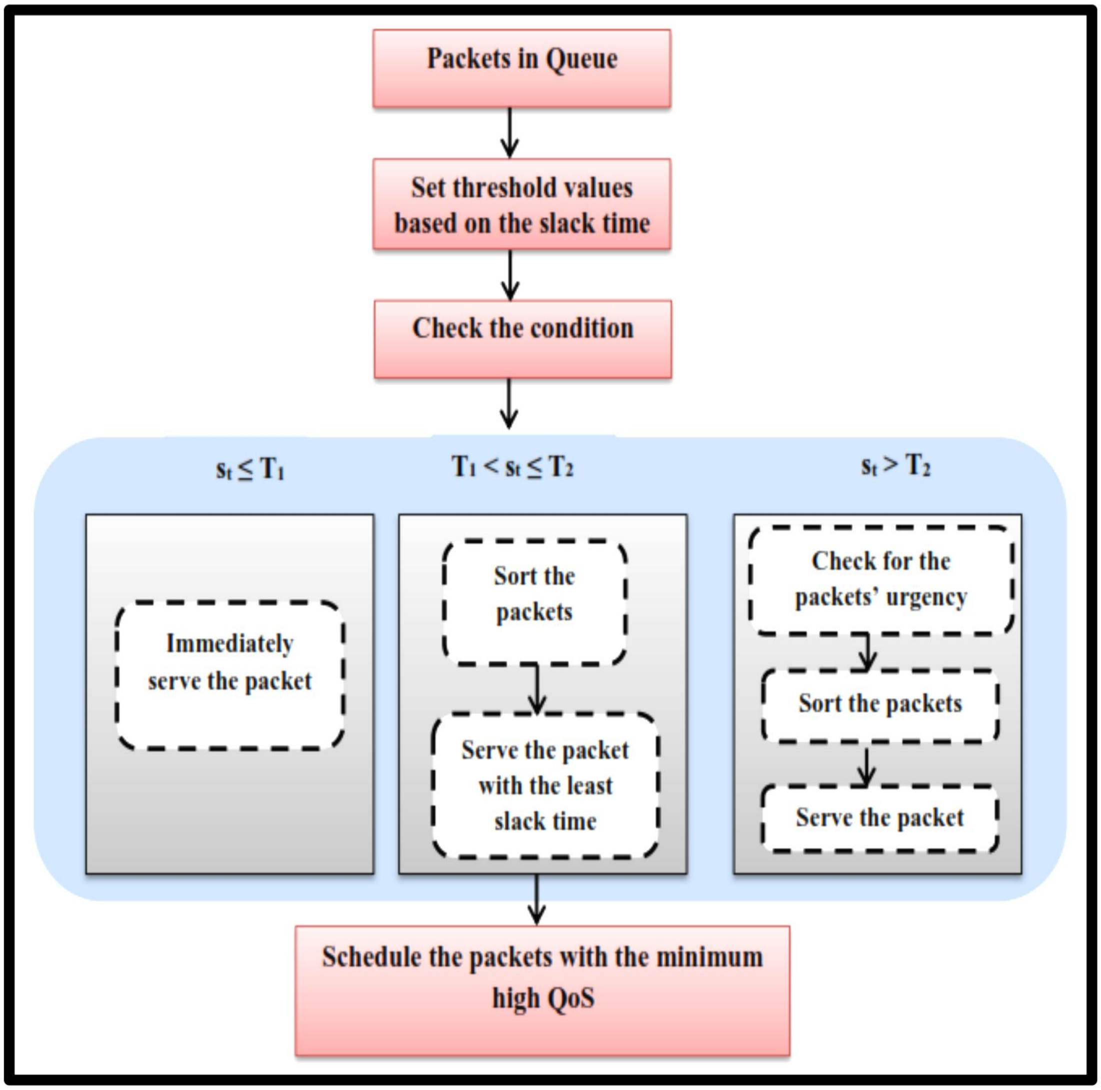


Figure 4.7 Working process of the MDPD-k scheduling algorithm

In equation (4.10), $D_p$represents the deadline of a packet, $t$is the current time, and c',the residual packet transmission time. An intermediate node in the path periodically calculatesthe slack time of packets,and then forwards the ones with the least slack time. When slack times of all the packets are equal, any one of them has to be randomly pickedand sentout. Theefficient scheme with the DPD-k scheduling algorithm is usedwhich is thenextendedas the Modified Dynamic Priority with Deadline Consideration (MDPD-k) scheduling approach. DPD packet scheduler sortsthe packets based on their priorities but the priority level canbe dynamically changed. Consequently, two different threshold values are set based on the remaining slack time.Thealgorithm can change the priority level of any waiting packet stored in the buffer andit has also the ability to perform partial sorting operations.

In the MDPD-k notation, *'k'*denotesthe degree.The algorithm sorts the first packets present in the buffer, *k* packets with the highest priority are scheduled orput into a waiting state in order to be later transmitted. It is decided for a packet stored in the header to be served or not depending upon its remaining slack time. For example, when the header has the t-units of remaining slack time (s_t) for a packet the t-units packets are compared with the two threshold values ($T1$ and $T2$, where $T1<T2$). The process of the packet scheduling algorithm isperformed based on the condition satisfied by the slack time (s_t). The conditions areas follows:

- $s_t \leq T_1$
- $T_1 < s_t \leq T_2$
- $s_t > T_2$

The working process of this MDPD-k algorithm is detailed below:

- If $s_t \leq T1$: Without considering the priority of a packet, it is immediately served as it is in a critical condition, otherwise, it will have no remaining slack time and would be considered as lost.

- If $T1 < s_t \leq T2$: With this situation, the packet is served based on the corresponding SPD-k scheduling. Thus, the first *k* packets are sorted and the ones with the highest priority will be served. The packetwhich is at the head of the buffer is then placed in its appropriate position by increasing its priority one level as a way of compensation for removing it from the head of the buffer which is the same for the DPD-k scheduling algorithm.

- If $s_t > T2$: Again, the same SPD-k scheduling technique is used to serve the packet. However, the remaining slack time of the packet located at the head of the buffer is still high; its priority remains unchanged.

1. Q← Φ; Q← Entering New Packets

2. For each packet calculate s_t from equation (4.3)

3. Calculate T_1 and T_2

T_1 = Min_ s_t

$T_2 = (\sum_{i=1}^{n} s_t) / n$

4. s_t of a pckt_header is

4.1.1 if ($s_t \leq T_1$)

then pckt_header→ served

end if

4.1.2 if($T_1 < s_t \leq T_2$)

then first k_pckts→ sorted andpckt_header→ served

end if

4.1.3 if ($s_t > T_2$)

if(pckt_header = urgent_pckt)

then pckt_header → served

else first k_pckts → sorted

then pckt_header → served

end if

end if

Figure 4.8 MDPD-K Scheduling Algorithm

Figure 4.8 presents a detailed explanation of the MDPD-k scheduling algorithm. Each node maintains the queue to randomly store the received packets. For each packet, the slack time is calculated by using equation (4.10). The threshold values are then calculated based on slack time, those values help in taking rational decision while serving packets to each node under various checking conditionswhere each packet's slack time iscompared to those threshold values. The following is a simple example of MDP-k scheduling algorithm:

The packets' initial input stage is presented as follows:

2	5	9	6	7	4	8	3

➢ *If $s_t \leq T1$:*

Those input packets arescheduled to nodes comparing their slack time with the threshold values set as*T1=2 ms, T2= 5.5 ms,* the degree of nodes isset to 4, and a packet in the header has a slack time set to 2. The scheduling process is then performed as follows:

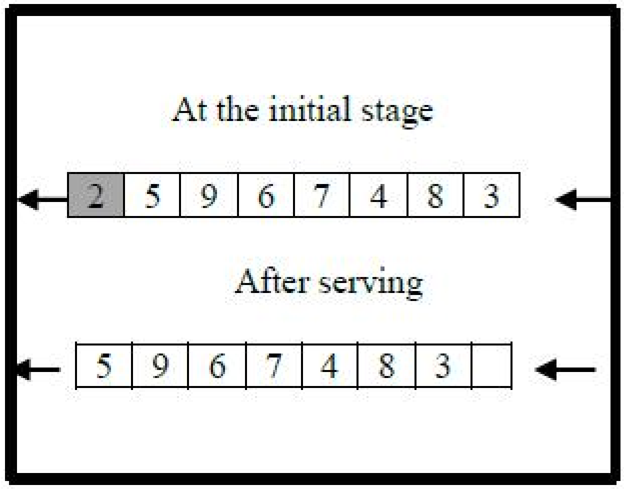


Figure 4.9 MDPD-4 Algorithm with st ≤ T_1

The given input has satisfied the first condition; the packet is then immediately scheduled.

- *If* $T1 < s_t \leq T2$:

Figure 4.10 illustrates the example of MDPD-k scheduling algorithms at the second stagewhere the packet at the head of the queue with the priority value of *7*hasa remaining slack time range of $T1 < s_t \leq T2$.The first 4packets are sorted according to the slack time. The header of the buffer is then reset with a packet having least slack time set to 2which is then immediately served.

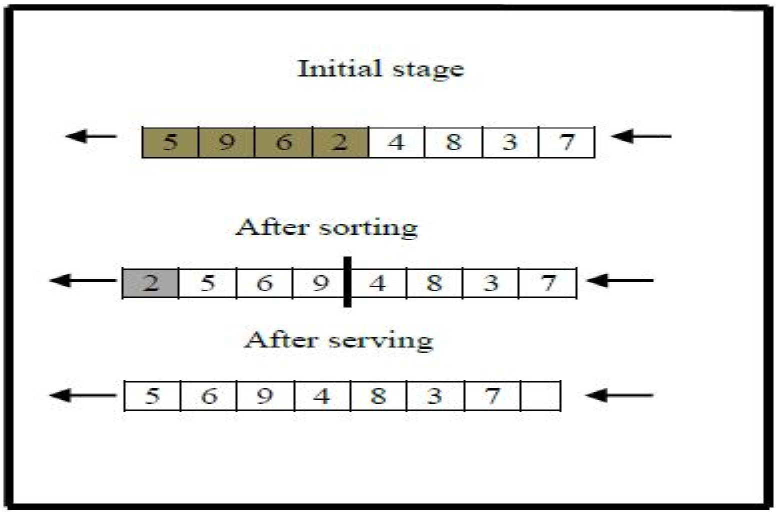


Figure 4.10 MDPD-4 algorithm with $T_1 < st \leq T_2$

➢ *If s_t> T2:*

At the last stage, the first input has the same value as the threshold, thenmoved to the third condition.First, it has to be checked whether the first packet i.e. 9 has to be sent immediately or not.

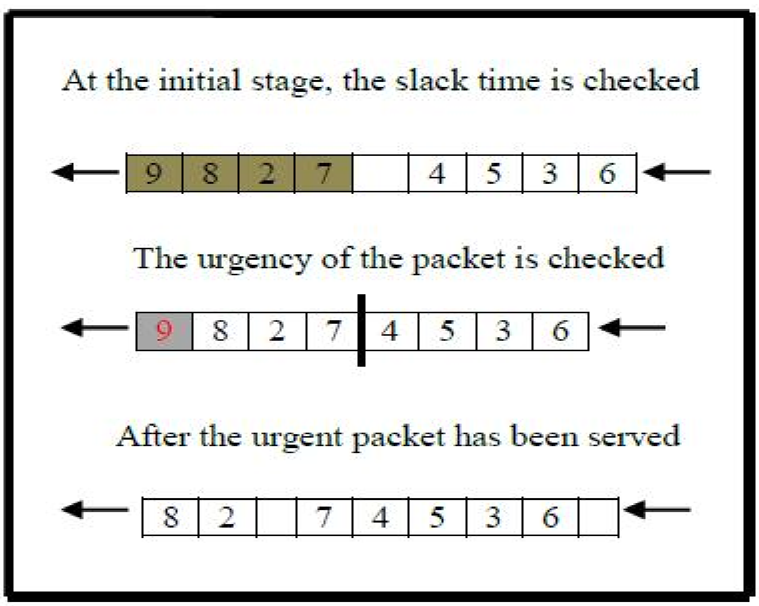


Figure 4.11 MDPD-4 algorithm with $st > T_2$

The 9 isurgent, therefore, it has to be immediately served.Otherwise, the packets are sorted based on slack time and allocatedaccording to the least slack time. The previous example clearly explainsthe working procedure of MDPD-k packet scheduling algorithm.

First of all, the given input is checked under three different conditions. If the first condition is satisfied the packet is immediately served otherwise it is checked with the second condition where the packets are sorted in ascending order of the least slack time and the first packet is immediately served. If the second condition is not satisfied, the third oneis automatically approached. At that stage, first of all, the packet is checked for its urgency, if so, the packetis allocated, otherwise, the processes are moved back to the second stage and executed. The threshold valuecalculation has been fully explained by Tamer (2006).

4.5 EXPERIMENTAL EVALUATION

This section demonstrates the sole property of GDAQM, the proposed protocol,which makes it more advantageous compared to the existing approaches namely EDGA, GA, QOD, and AODV with GA. A short overview of those protocols is given below:

Genetic Algorithm for Energy-efficient Delay-constrained multicast routing (EDGA]

This routing mechanism uses a genetic algorithmwhich, with the help of efficient delay-constrained multicast routing features is able to find out an optimal path. This algorithm is a source-based protocolwhich takes into account the energy consumed at each node as well as the end-to-end delay for route selection criterion. It applies crossover and mutation operations directly on treeswhich simplify the coding operation and omits the coding/decoding process. The heuristic mutation technique can improve the total energy consumed at the multicast tree. This unique property istaken into account in the proposed study for performing an efficient coding/decoding process (Lu and Zhu (2013)).

Genetic Algorithm, Energy-GA

Energy-GA proposed by Prasanna et al. (2014) is both energy-efficient genetic mechanism and a source-based algorithmwhich takes into account the energy consumption as well as end-to-end delay during the route selection processes. This algorithm applies crossover and mutation operations directly on treeswhich simplifies the coding operation and omits the coding/decoding processes. Compared to LDT (Least Delay Multicast Tree algorithm) approach, the simulation results revealed that this algorithm is efficient in discovering Multicast QoS path in a dynamic environment. Genetic Algorithm (GA) proposed by Chandra and Reddy

(2014)basedon the route selection protocol to solve the multi-constrained QoS routeis used in this study. It identifies the optimal route with population initialization, crossover, mutation, and fitness function calculation. QoS constraints consistof the end-to-end delay, bandwidth, packet loss rate, node connectivity index (Ni), and dynamic resource availability. Compared with AOMDV, results showed that GA was outperforming.

AODV with GA and QOD

Lafta et al. (2014) introduced a new technique by using the concept of Genetic Algorithm (GA) with AODV protocol to make a routing decision in computer networks.The main purpose of the study was to find out an optimal path between source and destination nodes at the same time increasing both QoS and throughput ratios. This algorithm was compared in performance with the AODV protocol; the results revealed that the proposed algorithm was better than the traditional AODV.

Li and Shen (2014) proposed a QoS-Oriented Distributed routing protocol (QOD) to enhance the QoS support capability of hybrid networks. QOD incorporates five different algorithms. Experimental results showed that the new algorithm can achieve high mobility-resilience, scalability, overhead, and a low transmission delay.QOD protocol incorporates LSF (Least Slack First) scheduling algorithm used in the DPD-k scheduling algorithm.

4.5.1 Simulation Setup

A detailed simulation model based on NS-2 (NS-2.35) wasused to model theexperiments.We chose Linux platform i.e. UBUNTU as it offers a number of programming development tools that can be used in the simulation process.The NS-2 associated tool i.e NAM was used for the animation purpose. We processed data contained in the generated output trace files by using the AWK tool. We used C++ at the backend side and oTcl as the frontend programming language.Table 1 shows the experimentalscenario and settings. 10 to 50 nodes were used for conducting the evaluations within an area of 1500mX1500m; the total time to complete the simulation is 100 seconds. The omnidirectional antenna and IEEE 802.11 MAC layerwereused and201 packetsmaintained in the queue. Nodes move at a speed ranging from 1 to 20 m/s with a random waypoint movement. Two-Ray Ground radio propagation model and the following three metricswereused to compare the performance of the proposed protocol with the existing ones; PDR (Packet Delivery Ratio), Throughput, Delay, and Energy. Those metrics are explainedbelow in detail:

Packet Delivery Ratio is the fraction of the number of delivered data packets to the destination. This fraction illustrates the level of the packet delivery. The greater value of the packet delivery ratio means the higher performance of the protocol.

Packet Delivery Fraction=∑ Number of received packets / ∑ Number of sent packets(4.11)

Throughputisthe total number of packets delivered over the total simulation time. It is represented in bits per second (bps).

Throughput = Received_data/DataTransmission Period(4.12)

End-to-end delay fraction isthe average time necessary for a packet to reach the destination. It may be caused by many factors such asroute discovery cycle and queuing process used during data packet transmission. Only data packets that have been successfully delivered to the destination are counted. The performance of the protocol is determined by the value of end-to-end delay; the lower ratio means the higher performance of the protocol.

End-to-end delay ratio=∑ (Packet-arrive time – Packet-send time) / ∑ Number of connections (4.13)

Energy: The energy model represents the energy level of nodes in the network. The energy model defined in a node has an initial value that is the level of energy the node has at the beginning of the simulationtermed as *initialEnergy*. In a simulation, the variable *energy_* represents the energy level in a node at any specified time. The value of *initialEnergy_* is passed as an input argument. A node loses a particular amount of energy for every packet transmitted and every packet received. As a result, the value of *initialEnergy_* in a node gets decreased. The energy consumption level of a node at any point of time of the simulation can be determined by finding the difference between the current *energy_* value and *initialEnergy_* value. If the energy level of a node reaches zero, it can no more receive nor transmit any packets. The energy level of a network can be determined by summing the entire nodes energy level in the network.

Power is the rate of doing work. It is equivalent to the amount of energy consumed per unit time.

*Energy= power * time* (4.14)

Parameter values:

Table 4.1 Simulation Metrics

Simulation Metrics	Values
Number of nodes	10, 20, 30, 40, and 50
Interface type	Phy/WirelessPhy
Channel	Wireless Channel
Mac type	Mac/802_11
Queue type	Queue/DropTail/PriQueue
Queue length	201 Packets
Antenna type	Omni Antenna
Propagation type	Two-Ray Ground
Size of packet	256-1280
Simulation time	100 seconds
Simulation Area	1500X1500 m

4. 5.2Discussion ofSimulation Results

A performance comparison is conducted for the proposed algorithm with the existing ones by varying the routing metrics.

A. Performance Evaluation With PDR

Table 4.2 Comparative results for PDR vs. Number of Nodes

Number of nodes	Packet Delivery Ratio [(%)]	
	GDAQM	AODV with GA
10	**85**	16
20	**75**	10
30	**84**	15

40	**80**	12.8
50	**72**	12

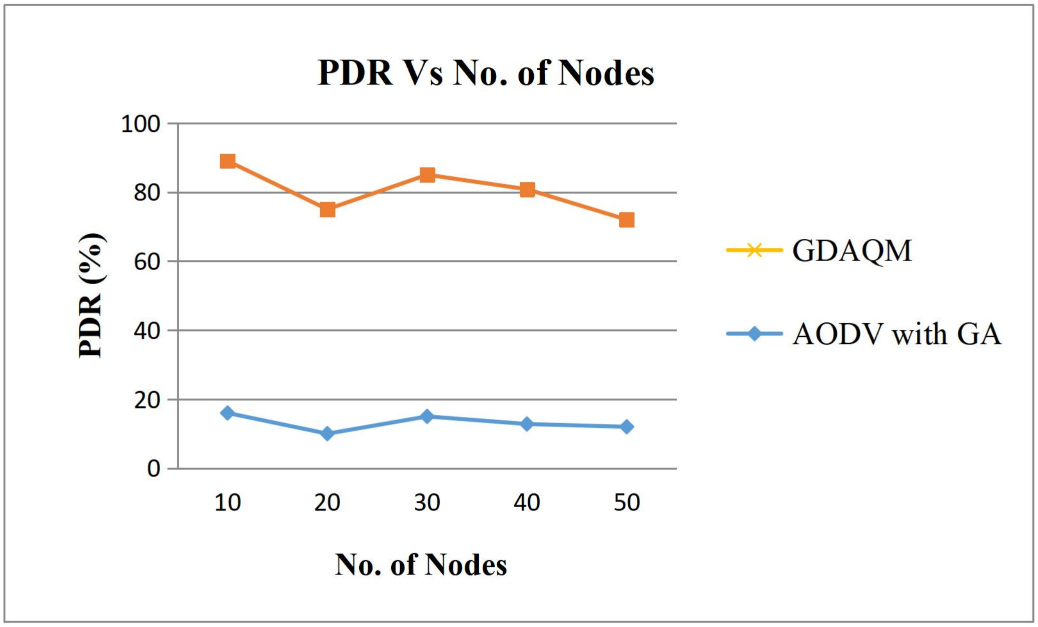


Figure 4.12 Comparative results forPDR vs. No. ofNodes

Table 4.2, Table 4.3, Figure 4.12, and Figure 4.13 exhibit the outcomes of the performance evaluation conducted considering PDR as the evaluating parameter metric. The experiments are organized into two different scenarios while considering the packet delivery ratio metric. The performances of the algorithms are first evaluated using PDR against the number of nodes ranging from 10 to 50. Then, the proposed scheme is evaluated with the Energy GA algorithm considering the node speed ranging from 0 to 20 m/s as shown in Figure 4.13.

Table 4.3 Comparative results for PDR vs.Nodes Speed

Speed [m/s]	Packet Delivery Ratio [(%)]	
	GDAQM	**Energy-GA**
0	**72**	61
10	**70**	60
20	**69**	58

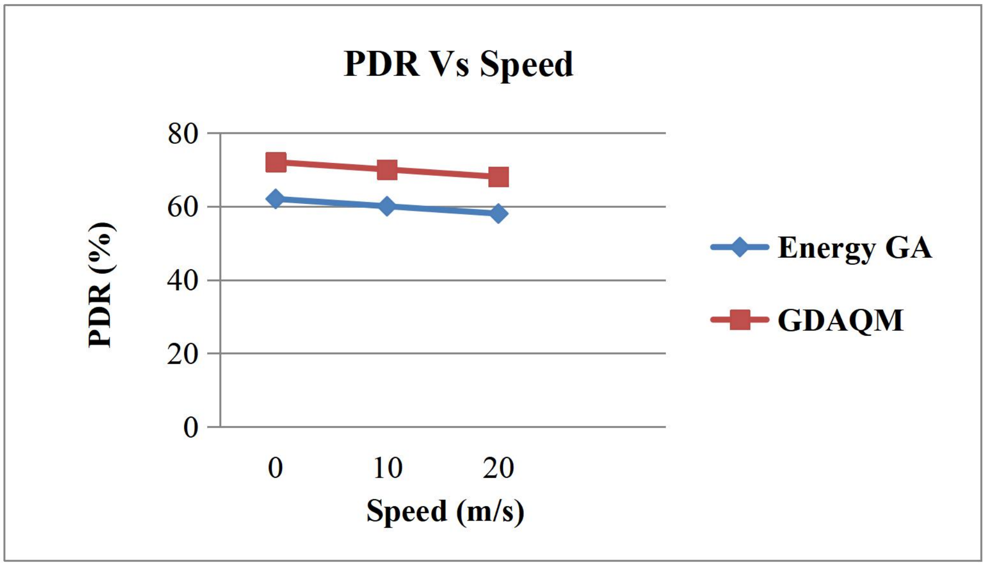


Figure 4.13 Comparative results forPDR vs. Nodes Speed

As shown in Figure 4.12, the proposed protocol GDAQM outperforms for a large number of nodes even if its PDR dropped at nearly to 75%. When the number of nodes is 20, PDRs startincreasing progressively as the number of nodes augments. One interesting observation for all the two algorithms is that their PDR did neither decrease nor increase very much as the number of nodes increased.The above trend is juxtaposed to the one in Figure 4.13 where PDRs of both Energy-GA and GDAQM decreased as the number of nodes augmented. This is due to the fact that the fraction of dropped packets increases due to various factors such ascongestion in the network with high speedy nodes, frequent route failures and breakswhich then results in a minimized number of received packets at the receiver. Nonetheless, GDAQM performs better in networks whose nodes are withboth small and high speeds. For both the performance evaluation scenarios (in Figure 4.12 and Figure 4.13), the simulation results show that the proposed algorithm performs better for all the cases studied.

B. Performance Evaluation with Throughput

Table 4.4 and Figure 4.14 entailing the comparative study of GDAQM with QOD reveals that the proposed protocol performs better than QOD in terms of throughput for small, medium, and large number of participating nodes. The overall observation about the performance of those two protocols is that their throughputs continually increased proportionally to the increasing number of nodes with a big difference in their throughput ratios. This is because GDAQM has chosen the maximum-bandwidth path, so, the network density did not affect the network throughput.

Table 4.4 Comparative results of Throughput vs. No. of Nodes

Number of nodes	Throughput [(kb/s)]	
	GDAQM	QOD
10	**119**	56
20	**121**	59
30	**125**	60
40	**134**	61
50	**140**	62

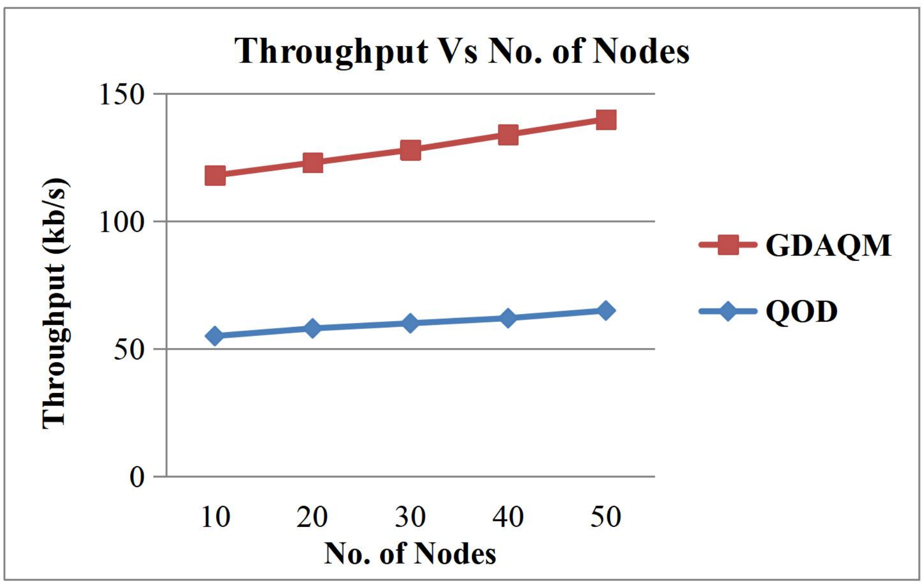


Figure 4.14 Comparative results of Throughput vs. No. of Nodes

Concerned with the throughput versus moving speed of the nodes, Table 4.5 and Figure 4.15present the comparative outcomes for bothprotocols (GDQAM and QOD). The throughput ratio is almost independent of the increasing speed of nodes as it remains unchanged for the overall simulation time. It is almost an exception as normally the higher mobility of nodes leads to frequent link breakages and the link re-establishment operation occurring cause a long transmission delay. Consequently, there would be a drop in the throughput ratio followed by a prolonged total transmission time. However, despite those issues, the proposed algorithm;

GDQAM which always selects the path with both the least-delayand maximum-bandwidth features performs better than QOD as the node speed did not apparently affectits performance, QOD always performs worse as its throughput is maintained lower at a static level both for small and high node speeds.

Table 4.5 Comparative result of Throughput vs. Nodes Speed

Speed [m/s]	Throughput [(kb/s)]	
	GDAQM	QOD
0	**130**	60
10	**130**	60
20	**125**	60

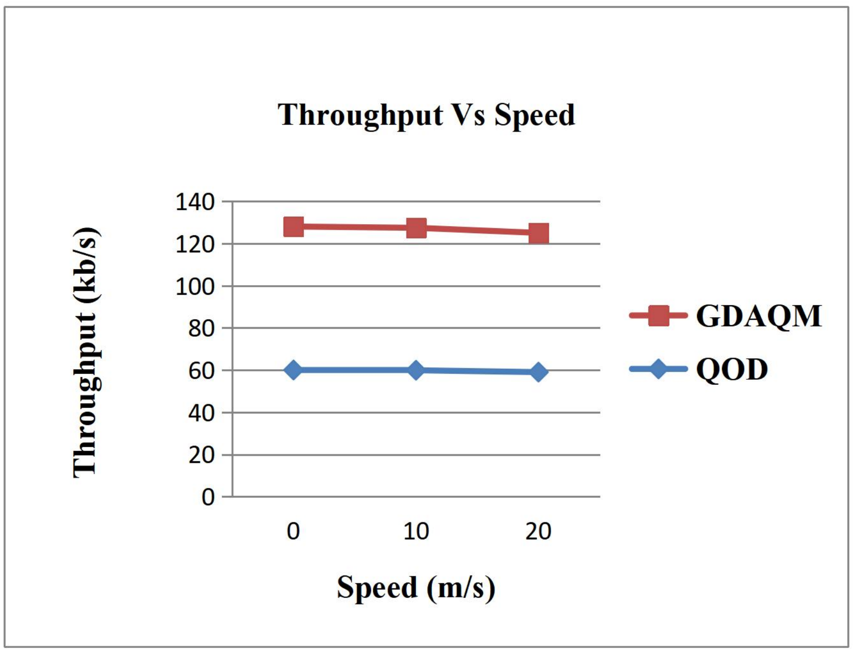


Figure 4.15 Performance evaluation of Throughput vs. Nodes Speed

C. Performance Evaluation with Delay

Table 4.6 Comparative result of Delay vs. No. of Nodes

Number of nodes	Delay [(secs)]				
	GDAQM	EDGA	Energy-GA	GA	AODV with GA
10	**2**	3	3	14	15
20	**3**	4	3.3	16.2	8
30	**3.8**	5	4	13.9	9
40	**4.1**	7	6	13.9	13
50	**6**	9	9	13.9	10

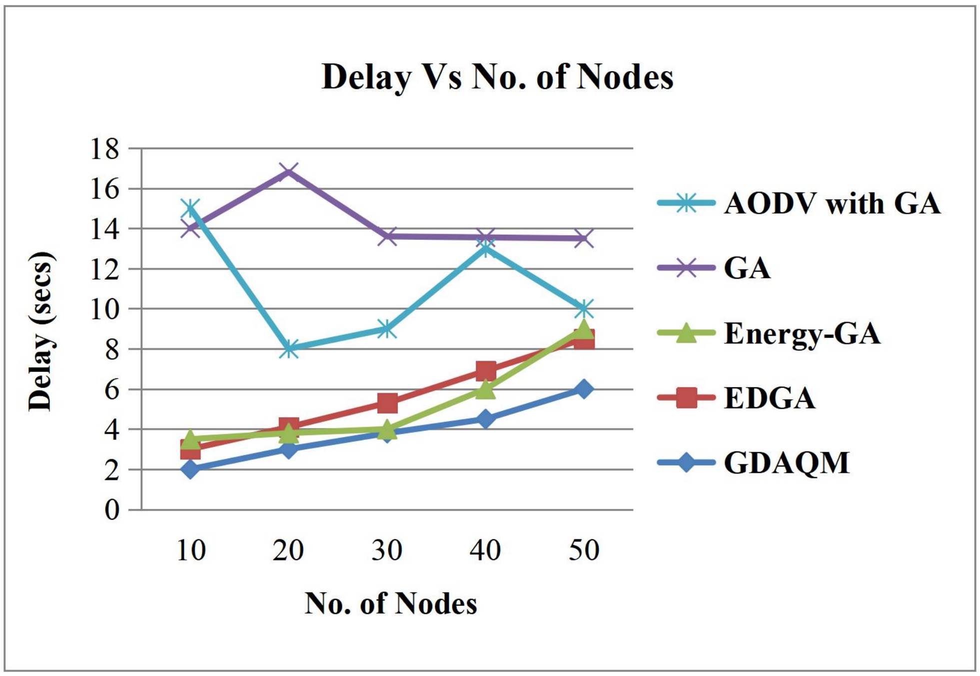


Figure 4.16 Comparative results of Delay vs. No. of Nodes

As seen in Table 4.6 and Figure 4.16, GDAQM protocol again outperformsthe other four algorithms as it maintains an average delay lower for the overall simulation time but with a minor difference with the Energy-GA and EDGA. GA performs badly as it maintains a very high average end-to-end delay. An important observation for GDAQM, EDGA, and Energy-GA is that their end-to-end delays almost augmentproportionally to the increasing number of the nodes which may be possibly due to more hops or queuing available in the network. Indeed, the same does not apply to the remaining two protocols i.e. AODV with GA and GAwhose delays are shaped in crisscross patterns.

C. Performance Evaluation with Energy

As long as the Energy parameter metric is concerned, Table 4.7 and Figure 4.17 exhibit the performance evaluation results of the proposed algorithm GDAQMcompared with GA. Generally, the genetic algorithm provides an efficient scheme for managing the power consumed by nodes because it is good at selecting an energy-efficient path. Nodes consume lower energy during the multicast processwhich mainly aims at finding routes to further achieve successfully multimedia data transmissions. Incorporating the genetic algorithm in the proposed protocol efficiently lowers the energy consumed by nodes dueto the tree structure coding/decoding mechanisms used within the protocol and the packet scheduling algorithm enhancement supplied during the packet transmission processes. Another observation is that the energy consumed by nodes is slightly increased with the increase in the number of nodes.

Table 4.7 Comparative Results of Energy vs. No. of Nodes

Number of nodes	**Energy [(Joule)]**	
	GDAQM	**GA**
10	**10**	10.8
20	**10.1**	10.8
30	**10.3**	11.6
40	**10.38**	11.1
50	**10.5**	12

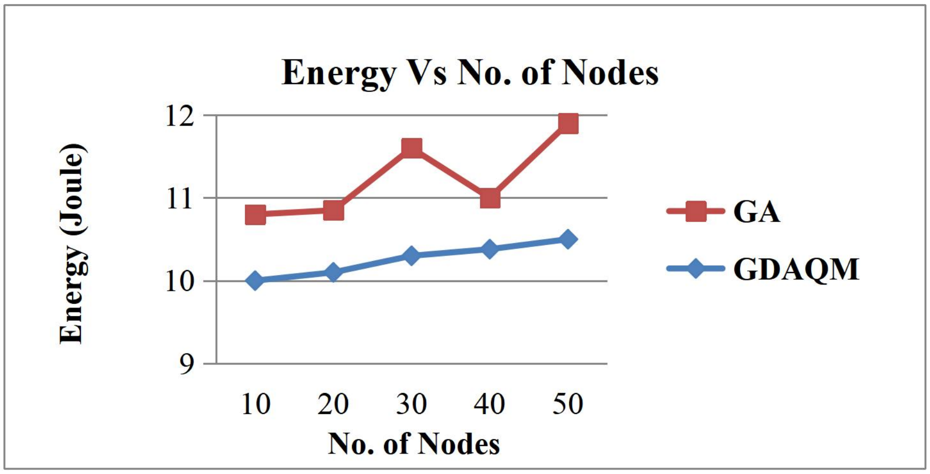


Figure 4.17 Simulation Outcomes of Energy vs. No. of Nodes

4.6 SUMMARY

In this chapter, a performance evaluation of the proposed algorithm; GDAQM (Genetic with DPD for Attaining high QoS in MANETs), a combination of different mechanisms namelythe Genetic Algorithm and MDPD-k (Modified DPD-k) scheduling algorithmhas been reported. The Genetic Algorithmwhich is a source-based techniquewas used to find out an optimal path between a source and multiple destinations (multicast technique).It achieved a very high QoS as it selectedthe least-cost, maximum-bandwidth, and energy-efficient path while MDPD-k scheduling algorithm was used for performing effective packet scheduling operations. Combined together, those two techniques resulted in a very effective algorithm able to achieve successful multimedia data transmission. During this evaluation, no coding/decoding process was performed; instead, the tree-structurebased encoding method, efficient crossover, and mutation techniques were used. Upon completing the route identification process using the Genetic Algorithm, an MDPD-k packet scheduling scheme was then used with which the packets were maintained in a queue and two different thresholds values were calculatedwhich were compared with each packet slack time to check whether that packet was to be urgently served or not using three different test conditions. The algorithm was very successful in providing fairness in the packet forwarding scheduling processes. A set of experiments was conducted on the GDAQM routing mechanism with the NS-2 simulation tool using PDR (Packet Delivery Ratio), Throughput, Delay, and Energy as the evaluating parameter metrics. For all the cases studied, varying the number of nodes and nodes speeds, the proposed scheme, GDAQM greatly outperformedother protocols, which was possible only since its multi-featured techniques were combined together in one protocol.

CHAPTER 5

NETWORK LIFETIME PREDICTION SECURE ROUTING MECHANISMENHANCED WITH PACKET SCHEDULINGFEATURES

Being infrastructureless, featured with wireless linkand dynamic topology, MANET faces various challenges during its overall operations. Most of those attributes inhibit the Quality of Service provision such asthe overall network lifetime degradation due to theshort lifetime of both node and linkcaused by the limited battery power of node making it dead or shutdown, resulting in both link and overall network lifetime degradation. Longer network lifetime alone is not enough to acquire high QoS in MANET as other problems may arise during route discovery, packet scheduling, and transmission processes. For example, malicious nodes may cause security breaches in the network and steal some traversing packets or misuse the network resources. An efficient packet scheduling mechanism (a key function of the Quality of Service) is also necessary during packet transmission as it manages the sequence of network packets in the transit and effectively manages queuesin the buffer.

In this chapter, an efficient algorithmwhich is a mixture of those previously mentioned QoS provision techniqueshas been proposed in order to acquire high Quality of Service for multimedia data transmission. For example, to increasethe networklifetime, the nodes energy consumption rate has to be reduced. Moreover,the lifetime of every node andlinkare predicted.Suchtechnique has been incorporated in the proposed algorithm under the name of Lifetime Prediction Routing mechanism. For security reasons, only the identifiedand reliable nodes (having the higher rate of reliability) are used for packet transmission purposes. The next process is with respect to the packet scheduling mechanismswhere a scheduling algorithm isused to avoid the routing overhead and network congestion events, minimized end-to-end delay, etc. The last process considersthe security provision mechanismwhich ensuresthe reliability of nodes through which the packets would pass to reach the destination; hence, an intrusion detection system is designed. Combining various QoS techniques in asingle protocol enabled the development of a very robust algorithm efficient in providing high QoS in MANETs.

5.1 LINK AND NODE LIFETIME PREDICTION

Lifetime prediction-based routing may be any on-demand source routing algorithm that can predict the lifetime of a node according to its residual energy and its past activities. These types of algorithms are often used to evaluate the lifetime of nodes and wireless links using well-defined routing metrics. The main objective of these protocols is to extend the service life of a mobile ad hoc network with dynamic topologies. To do so, they choose favorable paths having the maximum link lifetime.

In MANET, a path between any two mobile nodes can contain multiple links in series. If those nodes do not have enough energy to maintain the link alive, that link can be broken; this breakage can also happen when a node moves out of the communication range. Link lifetime means "How long the link will stay alive without causing any failure in the network". Consider the example: Let p be a route for packet transmissionwhich consists of n links. Assume that Ω represents the set of all nodes in route p and Ψ denotes a set of all possible connections in route p, the lifetime of route p can be expressed as:

$$Tp = min\ (TNi, TCi) \quad (5.1)$$

$Ni \in \Omega,\ Ci \in \Psi$

From the above equation, parameters are denoted as follows:

TNi refers to the estimated battery lifetime of the node Ni

TCi refers to the estimated lifetime of the connectionCi.

The lifetime of route p is expressed as the minimum value of the lifetime of both the nodes and connections involved in route p.

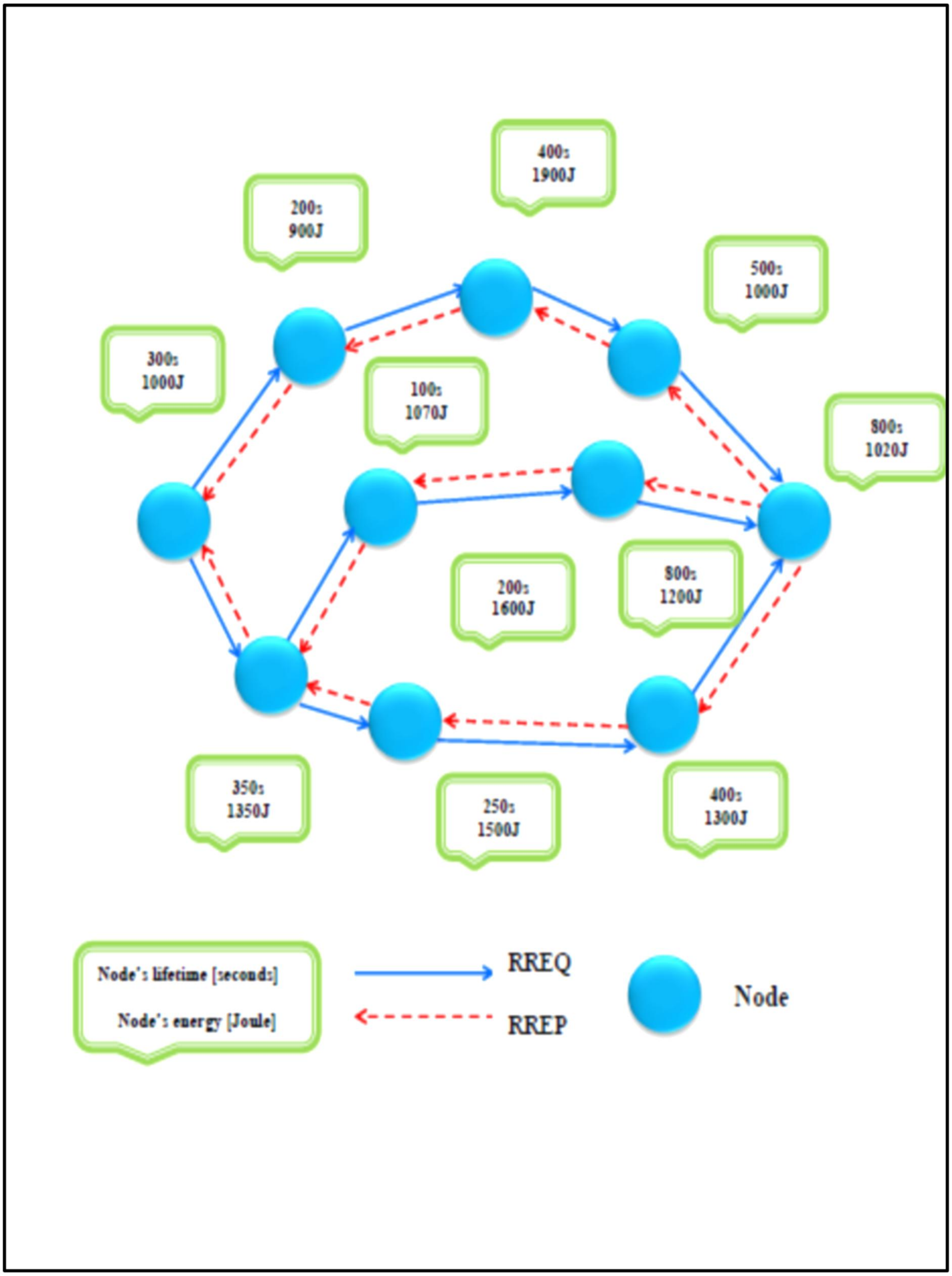


Figure 5.1 Route Setup Process in MANET

As seen in Figure 5.1, the node lifetime depends on its residual energywhich in turn depends on energy drain rate; these routing algorithms often select a path among the available multiple ones consisting of nodes that may survive for the longest time. Energy drain rate of a node is affected not only by its own but also by its neighboring data flows. The node's working mode also affects the draining rate of energy at that node, for example, when in a given network, there are two nodes which have the same amount of residual energy and one is in the active state and the other one is in inactive or waiting mode. The node in an active mode will exhaust more power than the one in the inactive state, so the formal one's overall lifetime is short compared to the latter one. To overcome all those negative issues, the node lifetime is often predicted based on both its residual energy and the information about its past activities (Priyadharshini et al. (2012)).

5.2 PACKET SCHEDULING IN MANETs

The delay-sensitive packet scheduling and routing algorithms are the important factors for improving the QoS in MANETs. These kinds of algorithms mainly aim to effectively deliver delay-sensitive multimedia data over multi-hop networks. Packet urgency, node urgency, and route urgency are calculated on the basis of end-to-end delay requirements. Based on these urgency metrics, the packet scheduling algorithm determines the transmission order of each packet to minimize the node urgency without unnecessary packet drop and establishes a route to minimize the derivatives of route urgency in order to maximize the number of packets delivered within the required end-to-end delay ratio (Vaidhegi et al. (2014)).

Urgency-Based Packet Scheduling Algorithms:

a. Packet Urgency:

Packet urgency *[urgency$_{pkt}$]* at the k^{th}node along the route*[R]* is defined as:

$$Urgency_{pkt}=\frac{e^{-a(Delay_{tol}-c)}}{1+e^{-a(Delay_{tol}-c)}},(5.2)$$

In general, $Urgency_{pkt}$ should be inversely proportional to $Delay_{tot.}$

Where$Delay_{tol}=Delay_{max}-Delay_{acc}^{k} / |R|-(k-1)$

From the above equations:

$Delay_{max}$ is the maximum tolerable end-to-end delay

$Delay_{acc}^{k}$ is the accumulated delay from the source node to the kth node

$|R|$ refers to the number of hops over the route

$Delay_{tol}$ is the tolerable delay/hop

a refers to the slope and c is the inflection point.

b. Node Urgency:

Node urgency [$Urgency_{node}$] is defined as the sum of packet urgency values in the buffer.

$$Urgency_{node}=\sum_{i=1}^{n_{pkt}} urgency_{pkt(i)} \quad (5.3)$$

Where n_{pkt} is the number of packets in the buffer and $urgency_{pkt(i)}$ is the packet urgency of the i_{th} packet in the buffer. A larger urgency value denotes that more urgent packets are there in the buffer.

c. Route Urgency:

Route urgency is defined as the sum of all node urgency values along the route

i.e. $$Urgency_{route}=\sum_{j\in R} urgency_{node(j)} \quad (5.4)$$

Where $Urgencynode_{(j)}$ refers to j^{th} node urgency. As the route urgency increases, it may become a congested path.

5.3 ROUTING PROCESS

Routing is the process of selecting paths in a network along which data packets will be sent. An ad hoc routing protocol is a convention, a standard that controls how nodes decide which way to route packets between computing devices in a mobile ad hoc network.

It is also the process of selecting optimum paths in the networkwhich is performed for many kinds of networks including electronic data networks, public switched telephone network, and transportation network. Electronic data networks perform routing using packet switching technology with hardware devices such as routers, gateways, bridges, firewall or switches. Various routing schemes are available in the literature (Sandhiya et al. (2016)):

- Unicast- delivers a message to a single node
- Anycast- delivers a message to any one of nodes available in the network but mostly the nearest to the source node is selected
- Multicast- delivers a message to more number of nodes i.e. interested nodes receive the message
- Broadcast- delivers a message to all the nodes in the network
- Geocast- delivers the message to a certain geographic area.

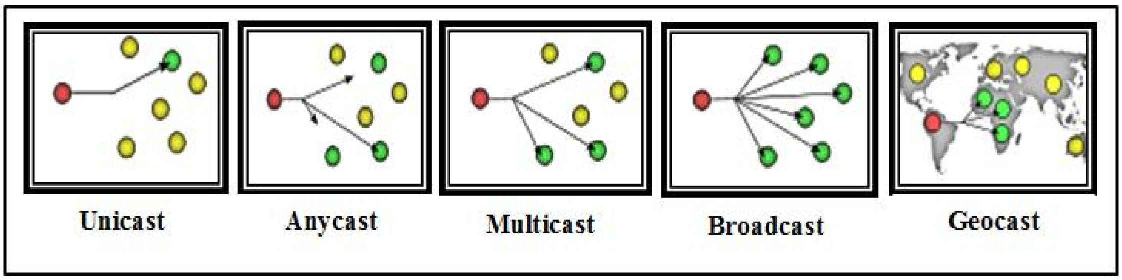


Figure 5.2 Routing Schemes

Various routing algorithms have been proposed in the literature andmost of them the use single-path mechanism i.e. only one path at a time. Multipath routing algorithms are better approaches as they can perform routing operations effectively by using alternate paths for sending packets to the destination. In general, the routing processes are classified into three categories including:

- Route discovery
- Route selection
- Route maintenance.

Route discovery:

Whenever a source needs to send data packets to the other nodes, it checks for the routeavailability in its routing table. If there is no established route between the source and destination nodes, it starts the route discovery process by broadcasting the Route Request (RREQ) packets to all the neighboring nodes.

Route selection:

If a particular path is selected for data packet transmission, it must satisfy the following requirements: minimum hop-count, high energy, minimum delay, and high stability.

Route maintenance:

Route Maintenance Phase is initiated whenever the route error packets are generated at a nodewhich is an indication that the relevant route has been broken, failed, or the node has moved out of the communication range. An alternative path is then chosen.

5.4 INTRUSION DETECTION

Intrusion is a set of actions that attempt to compromise the integrity, confidentiality, or availability of a resource and an intrusion detection schemeis a system for detecting such intrusions. It is a security-based technology that attempts to identify those who are trying to break into andmisuse a system without any prior authorization and those who have legitimate access to the system but are mistreating their privileges. In Monitoring-based Intrusion Detection, each node monitors the forwarding behavior of its neighboring nodes. In most cases, a node only monitors its next hop in a route. Totally, there are three types of components available in intrusion detection system i.e. data collection, detection, and response (Kumar et al. (2013)).

5.4.1 Anomaly Detection Systems

An anomaly-based intrusion detection systemis an intrusion detection system for detecting both network and computer intrusionsand misuses by monitoring system activity and classifying it as either normal or anomalous.

5.4.2 Misuse Detection Systems

Misuse detection is an approach to detect computer attacks. In a misuse detection approach, abnormal system behavior is defined first, and then, all the other behaviors are defined as normal.

5.4.3 Specification-based Detection Systems

Specification-based detection relies on program specifications that describe the intended behavior of security-critical programs. The monitoring of executing programs involves detecting the deviations of their behavior from these specifications rather than detecting the occurrence of specific attack patterns. Thus, attacks can be detected even though they may not previously have been encountered. Earlier efforts focused on sequential programsand their intended behaviors were specified in terms of a static set of allowable operations.

5.4.4 General Characteristics of Intrusion Detection Systems

An Intrusion Detection System can be defined as a device or an application with the capabilities of monitoring a network either wireless or wired for malicious events such aspolicy violation. The outcomes of this analysis are then reported to a central manager or collected centrally by a Security Information and Event Management System which combines outputs from multiple sources and using alarm filtering mechanisms to extract the malicious events from false alarms.

Some inherent properties of MANETs make conventional intrusion detection systems inefficient and ineffective. For example, new intrusions continually emerge and new techniques are needed to defend against them. Since there are always new intrusions that cannot be prevented, IDS is introduced to detect possible violations of a security policy by monitoring system activities and responses. IDSs are aptly called the second line of defense since IDS comes into the picture after an intrusion has occurred. If the attack is detected once it comes into the network, a response can be initiated to prevent or minimize the damage to the system. It also helps prevention techniques to improve by providing information about the intrusion techniques.

5.4.5 Taxonomy of Intrusion Detection Systems

There are three main components of IDS: data collection, detection, and response. The data collection component is responsible for collecting and pre-processing data tasks: transferring data to a common format, data storage, and sending data to the detection module.

5.4.6 Intrusion Detection Issues in MANETs

Even though there are many proposed IDSs for wired networks, MANET specific features make conventional IDSsineffective and inefficient for this new environment. Consequently, researchers have been working recently on developing new IDSs for MANETs or changing the current IDSs to be applicable to MANETs. There are new issueswhich should be taken into account when a new ID is being designed for MANETs (Vishwakarma and Chopra (2012)).

5.5 PROBLEM STATEMENT

A Mobile Ad hoc Network (MANET) is an infrastructureless wireless network meaning that the topology is dynamically created without any central authority such asa router, access point, etc. Being a wireless network withthedynamic topology and lack of any management scheme, MANET faces various challenges. The main concern is the network overall lifetime as its mobile nodes are battery-powered and constrained by limited battery power lifetime; this issue makes a node's active state short due to unrealistic shutdown or restart. This tragic event affects the reliable data transmission operations from one end to another, thus, resulting in the Quality of Service degradation in the whole network (Marcel and Vetrivelan, 2015).

The second issue associated with nodes in MANETs is the situation where they fall out of the radio frequency rangesresulting in unexpected route breaks which, in turn, end up in various problems such as packet drop, increased end-to-end delay ratio, etc.

Another major problem faced in MANETsis concerned with packet priorities before their transmission processes start.Some poor protocols do not have those scheduling features required to avoid both the congestion and routing overhead events during their transfer processes. The serious problemwhich sometimes is not taken into consideration by various researchersis the security issueswhere packets face security breaches in the network caused by some intruders or some malicious nodes. To solve those previously mentioned negative issues, a new routing mechanismMARMAQS (Multi-Algorithm Routing Mechanism for Acquiring high Quality of Service) has been proposedfor MANET.The algorithm is a combination of various techniques, each one designed to contain those previously mentioned corresponding problems and thus, the proposed scheme highly increases the QoS ratio in the whole network.

5.6 METHODOLOGY

5.6.1 Proposed Work

The proposed approach mainly aims at improving the provision of QoS in MANETs; this isachieved by enhancing various QoS parameters namelythe increased network lifetime, throughput, Packet Delivery Ratio (PDR), and reliability but minimizing both the end-to-end delay and routing overhead. With respect to the lifetime parameter metric, both the link and node lifetimes are considered by extending each node battery power, thus, reducing packet drop ratio.Packet drop ratio maybe caused by both the link failure and breaks due to the death of any participating nodecaused by the lack of energy or the one having been fallen out of the communication range. Thus, improvements are made to attain a high network performance.

MARMAQS is a complex protocol consisting of Routing, Packet scheduling, and Intrusion monitoring mechanisms. Routing is related to the packet transmission processes consisting of route discovery, route selection, transmission operations, and route maintenance while the packet scheduling techniques are used to schedule the packets to avoid both the congestion and routing overhead while the transmission is in progress. Finally, the intrusion monitoring process deals with the problem related to the packet loss in the networkcaused by various security breaches. The mixture of those various techniques made the proposed scheme very robust as it achieves a high QoS provision in MANETs. The following section describes those techniques combined in the proposed scheme.

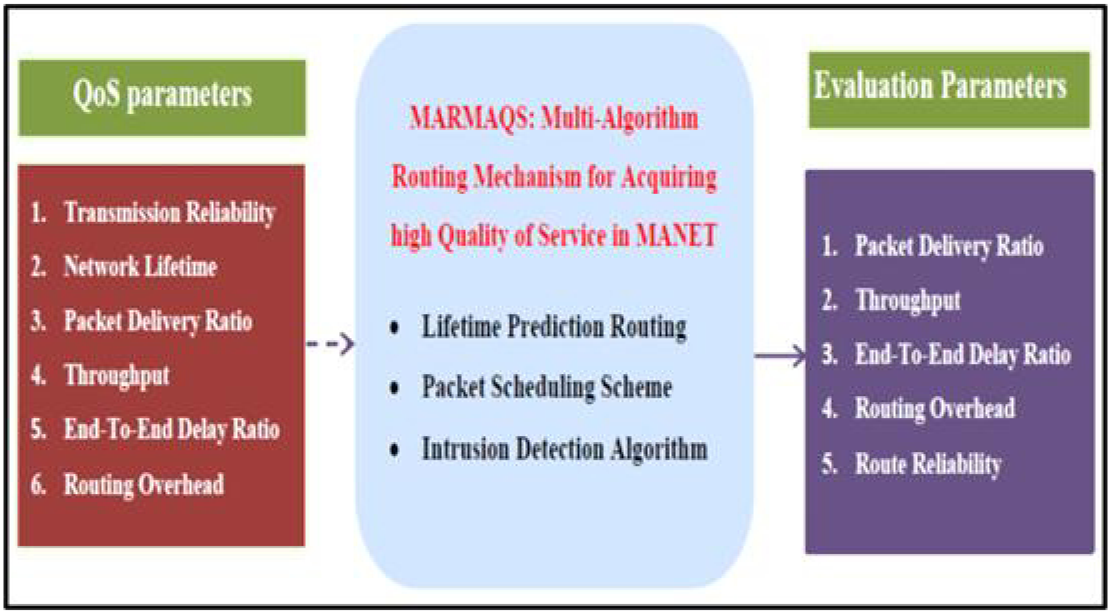


Figure 5.3 Overview of the proposed work

Routing

Finding an appropriate route aiming at establishing a communication channel between nodes while exchanging messages is the main goal of deploying a MANET.Upon obtaining the best route, information is then relayed from one end to another traversing various intermediate nodes and links, hence, multi-hop and multi-path routing are achieved.

In this work, a new mechanism has been introduced,*Lifetime Prediction Routing (LPR)* algorithm capable of highly achieving routing processes due to its ability to take into account both the node and link lifetime prediction mechanisms.Features required to predict the future transmission successare alsoconsidered as theyhelp in avoiding various problems related to routing such asincreased packet drop and end-to-end delay and both decreased transmission reliability and packet delivery ratio, etc. (Priyadharshini et al. (2012))

The link lifetime isdefined as follows:

$$LLT_i = min\,(LC_i, N_{i-1}, N_i)(5.5)$$

Whilethe lifetime of a node located along a given path is defined by,

$$T_{N_i} = \frac{e_i^{NT}}{EV_i^N}, t \in [NT, (N+1)T](5.6)$$

Inequation (5.5) and equation (5.6),

LLT_i represents the lifetime of a link

LC_i represents a connection between two nodes N_{i-1} and N_i

T_{N_i} represents the lifetime of a node

$EV_i^N$is the energy depletion at the N^{th} period of time and e_i^{NT}representsthe residual energy value.

Upon determining the lifetime of both the nodes and their relevant connecting links, the root nodes' values in the routing table are updatedaccordingly. Using the hop-count methods, the best paths are then calculated to route packets through, and finally, packet transmission processes take place using the selected best routes. Figure 5.5 exhibits the Lifetime Prediction Routing mechanism's full processes.

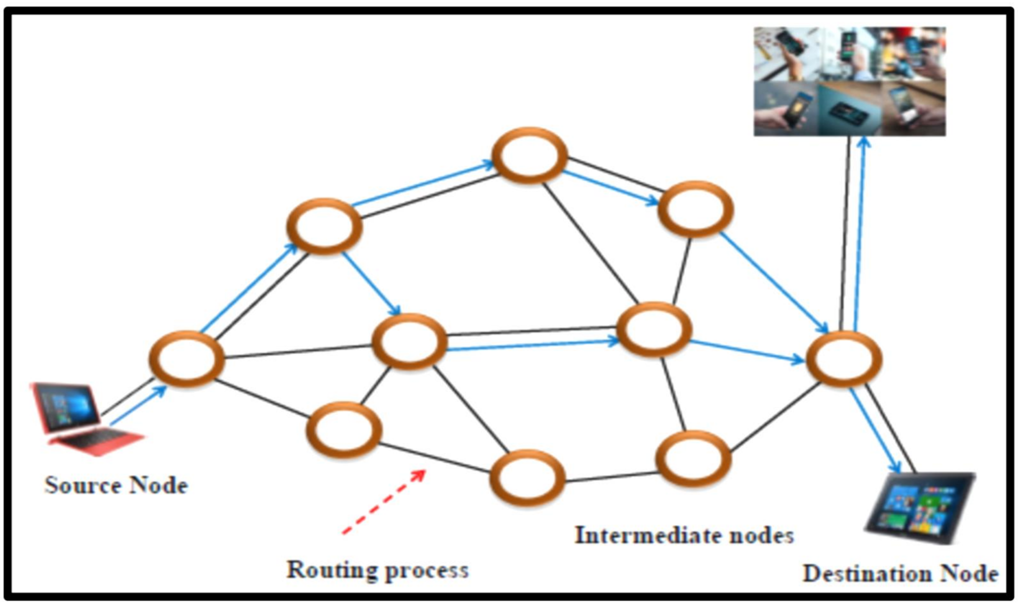


Figure 5.4 Routing and network topology structure inthe proposed scheme

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BEGIN

Inputs: Every node Lifetime (T_{N_i}), every link Lifetime (LLT_i), RT, Req (S-id, D-id, BC-id, Hp), and Rep (S-id, D-id, Hp, T_{N_i})

Output: Packet transmission using the selected best path

Begin

Step 1: S_n Req

Step 2: if ($D_n \rightarrow$Rep)

Update RT

end if

Step 3: Choose P

Step 4: P must have fewer Hp

Step 5: P €LLT_i&& T_{N_i}

Step 6: if (LLT_i&& T_{N_i} is high for P)

Transmit I → D_n

Rep from S_n

else

Select another P, P € LLT_i

Transmit I → D_n

Rep from S

end if

END

==

Figure 5.5 Lifetime Prediction Routing algorithm

The pseudocode inFigure 5.5explains all about the full routing process of theproposed scheme. S_n isthe source node, D_n is the destination node, *S-id*is the source node Id*, D-id*is the destination node Id, *Hp*isthe hop-count, *P* is the path from a given sender node to a respective receiver node, *RT* is the routing table, *Req* is the initial request packet, *Rep* isthe reply packet from the destination node, *BC-id* is the broadcast Id for every *Req*, and *I* is the information to be transmitted to the destination node. Nodes are initially supplied with higher energies and their lifetimes arecalculated usingequation (5.6). A*Req (S-id, D-id, BC-id, Hp)* isfirst transmitted to the neighboring nodes.

Each node is then checked for the conditions included in the transmitted information in the packetwhen it satisfiesthose conditions; it sends a reply packet in the form of *Rep (S-id, D-id, Hp,* T_{N_i}*)* to the sender node. All replies from all the neighbor nodes areprocessed and the routing table (RT) is then updated as shown in Table 5.1. The selected best path must satisfy the following two conditions: having a lesser number of hops and both higher link and node lifetimes oran alternative path from the *RT* satisfying those conditions is chosen instead.

The technique isvery successful in avoiding the excessive packet loss ratio during the packet transmission processes even if some additional problemsmay arise such as the overhead incurred in the network and congestion events due to the simultaneous transmission processes. Therefore, a scheduling schemeisrequired to restrain those negative issues, thus, a new packet scheduling algorithm is proposed and described in the next section.

Table 5.1 Routing Table

Lifetime(j)	*Nodes*	*1*	*2*	*3*	*. . .*	*N*
1000	**1**	**0**	**1**	**1**	**. . .**	**6**
1000	**2**	**1**	**0**	**2**	**. . .**	**4**
1000	**3**	**1**	**2**	**0**	**. . .**	**7**
1000	**.**	**.**	**.**	**.**	**.**	**.**
1000	**.**	**.**	**.**	**.**	**.**	**.**
1000	**.**	**.**	**.**	**.**	**.**	**.**
1000	**N**	**6**	**4**	**7**	**. . .**	**0**

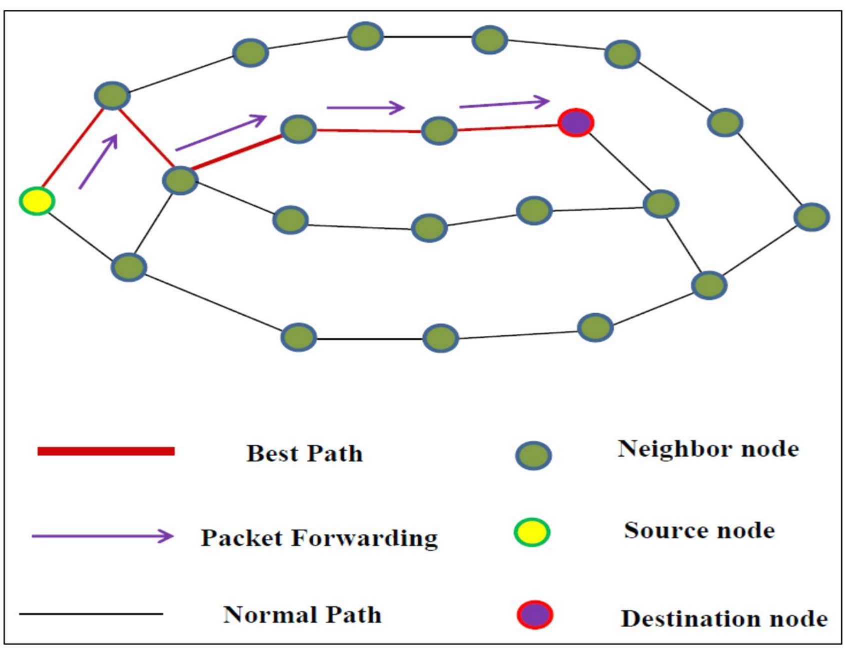


Figure 5.6 Lifetime Prediction Routing

Packet Scheduling

Packet scheduling is another important mechanism that enhances the Quality of Service (QoS) provision in MANETs. Using this technique, priorities are always assigned to traffic flows. In this chapter, a new scheduling algorithm is introduced; the Urgency-based Packet Scheduling (UPS) in which the link and node lifetime parameter values derived from equation (5.5) and equation (5.6) are used for both packet scheduling and transmission purposes. A route is initially prepared which will be used for transmitting the packet whose both link and node lifetimes aren't high. Packet id is prioritized during the transmission processes using packet urgency and node urgency parameters. The packet urgency can be calculated as follows:

$$U_{pack}(t) = F_{ur}\left(\frac{d_{res}(t)}{D_{mx}}\right)(5.7)$$

Where $d_{res}(t) = D_{mx} - d_{acc}^{i}(t)$

D_{mx} is the maximum tolerable end-to-end delaywhich isthe cumulative delay from the source node to the ith node, $d_{res}(t)$ isthe residual delay that satisfiesthe end-to-end delay requirement over the remaining hops. When a packet hassmaller $d_{res}(t)$, then it is immediately transmitted to the destination node (high priority). The node urgency is calculated as follows:

$$U_{node}(t) = \sum_{j \in R} U_{node(j)}(t)(5.8)$$

Urgency-based Packet Scheduling (UPS) associated with this process is shown in both Figure 5.*7* andFigure 5.8. Figure 5.7 depicts the process of the proposed packet scheduling algorithm. In this figure, 1, 2, 3 … *n*represent each packet number, *'A', 'B', 'C'*are their transmission priorities while n_1, n_2, n_3... represent the node numbers through which packets are transmitted within the network. $U_{pack}(t)$ is the calculated urgency of packets to be transmitted and $U_{node}(t)$ is theurgencyof node calculated for all the nodes whose packet urgency is high. In this research work, when both the packet and node urgencies are high at a given time, they are then given the first priority *'A'* during the packet transmission processes. When the urgency of a packet is high while the node's is low at a specific time, their transmission priority is set to the second level *'B'*. Finally, when the urgencies of both the packet and node are low at a given time, the third priority *'C'*is allotted.

Upon completing the packet and the node urgency calculations, the transmission process takesplace with the first priority given to an urgent packet (from equation (5.7)) which has to pass at the urgent node (from equation (5.8)) having a higher lifetime (from equation (5.6)) through a link whose lifetime is high (from equation (5.5)) and having fewer hop-counts. The scheduling scheme combined with the Lifetime Prediction Routing algorithm almost avoids the delay incurred during the sensitive data transmission processes resulting in minimized packets drop ratiocaused by both routing overhead and some congestion events.

Inputs: P = {1, 2, 3 … n}, Priority = {'A', 'B', 'C'}, Nodes = {n_1, n_2, n_3…}
Output: Packet transmission
Begin
Step 1: S_n P to D_n
Step 2: calculate $U_{pack}(t)$ ¥ P
Step 3: calculate $U_{node}(t)$ ¥ Nodes
Step 4: if ($U_{pack}(t)$ && $U_{node}(t)$ is higher)
        $U_{pack}(t)$ && $U_{node}(t)$== 'A'
          Transmit p→D_n
      Else if (($U_{pack}(t)$ is higher) && ($U_{node}(t)$ is lower))
            $U_{pack}(t)$ && $U_{node}(t)$== 'B'
            Transmit p→D_n
      Else if (($U_{pack}(t)$ is lower) && ($U_{node}(t)$ is lower))
        $U_{pack}(t)$ && $U_{node}(t)$== 'C'
        Transmit p→D_n
    End if
    End if
    End if
End

Figure 5.7 Urgency-based Packet Scheduling Algorithm

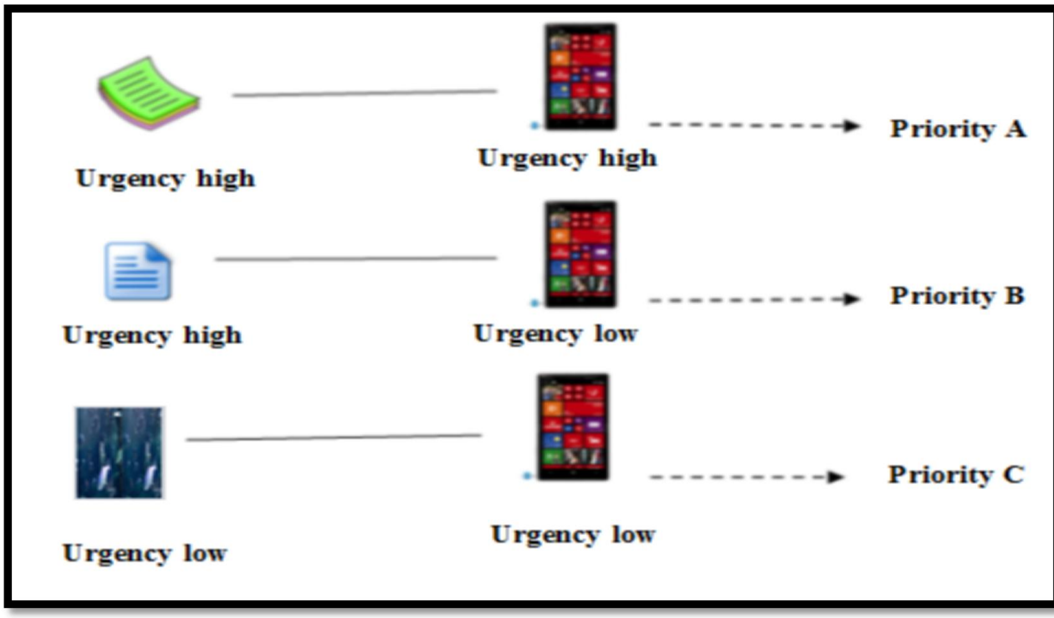


Figure 5.8 Urgency-based Packet Scheduling (UPS)

Intrusion monitoring

Intrusion detection and monitoring system is a security management scheme for both wired and wireless networks. It can be either a device or software application which monitors the network activities aiming at finding malicious or policy violation events and produces electronic reports to the management agents. The main process involves the information gathering and analyzing operations from several areas of the networkwhich identify security breaches involving both the intrusions and network misuse. In this work, the reliability of a networkis increased using the same approach by analyzing the behavior of every node available in the network in order to achieve highly reliable end-to-end transmissionresulting in a significant increase in the Quality of Service in MANETs.

Due to the lack of anycentral manager in MANETs, every node willact as a network monitoring agent, it verifies the behavior of neighboring nodes before forwarding data packets to them using the watchdog technique, the monitoring operation areperformed forthe next hopping within the network. The outcomes of the monitoring process arekept at each node if any malicious node is found along the path towards the destination.The monitoring nodes then send an alarm signal to the sender instructing it to choose an alternate path **(**Kumar et al. (2013)).

5.7 EXPERIMENTAL EVALUATION

This section describes various approaches used in performance evaluation to prove how the proposed scheme outperforms in successfully providing high QoS in MANETs. Those includeParticle Swarm Optimization (PSO) based Node and Link Lifetime Prediction (PNLP), Improved Routing Security (IRS), and Lifetime Prediction Routing in Mobile Ad hoc Networks (LPR).

Particle Swarm Intelligence Based Node and Link LifeTime Prediction [PNLP]

Using this mechanism, both node and link lifetimes are predicted using parameters such asrelative mobility of nodes, energy drain rate, etc. The fuzzy and fuzzified rules are used to make relevant decisions based on each node status; the resulted informationis then shared among all the participating nodes in the network. The checking process then verifiesthe status of each node before the transmission process begins, the handover between a weak node and a strong one canoccur during the route recovery process (Manickavelu and Vaidyanathan (2014)).

Improved Routing Security [IRS]

IRS is a security protocol which has been proposed for MANETs, it successfully provides the routing protocol security by allotting a pattern key to every node and each one wishing to communicate first checksfor both the identity and validity of its partner before the communication starts. For the communication to take place, the pattern key of both the sender and receiver are to be mixed to create another encryption key and then used for both encryption and decryption operations.Thescheme drasticallyenhancesthe performance ofMANETs (Awasthi et al. (2015)).

Life Time Prediction Routing [LPR]

LPR is a reactive routing protocol that has the ability to predict the battery lifetime based on its past activity using a Simple Moving Average (SMA) predictor, it also accounts for the rate of energy discharge. It isa dynamic distributed load balancing approach that avoidspower-congested nodes and chooses paths that are lightly loaded i.e. whose lifetime ismaximizedwhich helpsLPR achieve minimum variance in energy levels of different nodes in the network. The routing protocol is very effective in extending the service life of MANETs consisting of a dynamic topology. It is achieved by performing local decisions with minimum overhead. A clear increase in the overall network lifetime is also attained (Maleki et al. (2003)).

5.7.1 Simulation Setup and Results

The materials and methodology used to compare the proposed scheme and the already existing ones are described in this section.A detailed simulation model based on NS-2 is used to model the four protocols namelythe proposed MARMAQS and the existing ones PNLP, LPR, andIRS. The NS-2 instructions are used to define the topology structure of the network and the motion mode of the nodes, to configure the service source and the receiver, and to create the statical data trace file. The network animator (nam) is used to graphically visualize the simulations. We used oTcl (Object Tool Command Language) as the frontend (i.e. user interface) and C++ as the backend running the actual simulation. For text processing, data extraction, and report generation, we used the AWK tool.

IEEE 802.11 for wireless LANs isused at the MAC layer with radio propagation model of Two-Ray Ground. 201 packets aremaintained in the queue. The network consists of 30 nodes within an area of 1500X1500 m with the maximum simulation time of 100 seconds. A random waypoint model isused to model the node movementswhich moveat a speed ranging between 1 and 20 m/s.

The following table depicts the parameter metrics used to compare theproposed scheme, MARMAQS with the existing ones.

Table 5.2 Simulation Parameters

Parameter	Values
Number of nodes	30
Interface type	Phy/WirelessPhy
Channel	Wireless Channel
Mac type	Mac/802_11
Queue type	Queue/DropTail/PriQueue
Queue length	201 Packets
Antenna type	Omni Antenna
Propagation type	TwoRay Ground
Size of packet	256-1280
Mechanism	MARMAQS
Traffic	CBR
Simulation area	1500M*1500M
Node mobility speed	1…20 m/s

5.7.2 Performance metrics

Theproposed algorithm is compared with the existing ones using the following parameter metrics:

- End-to-End Delay
- Packet Delivery Ratio (PDR)
- Throughput
- Route Reliability
- Routing Overhead.

5.7.3 Comparative Analysis

The performance of theproposed scheme compared with the existing ones in term of End-to-End Delay is depicted in Table 5.3 and Figure 5.10 while the outcomes of the performance evaluation with PDR are presented in Table 5.4 and Figure 5.11. Table 5.5 and Figure 5.12 exhibit the performance of the compared protocols in term of throughput.The comparison using the route reliability is shown in both Table 5.6 and Figure 5.13.Finally, Table 5.7 and Figure 5.14 contain the comparative results using the Routing Overhead parameter.

End-to-End Delay

End-to-end delay ratio isthe average time necessary for a packet to reach the destination. The delay might be caused by many factors such as route discovery cycle and queuing process used during the data packet transmission operations. Only data packets that have been successfully delivered to the destination arecounted. The performance of the protocol isdetermined by the value of the end-to-end delay; the lower ratio means the higher performance of the protocol.

$$\textit{End-to-End Delay} = \frac{\sum(Arrival\ time - Send\ time)}{\sum Number\ of\ connections} \quad (5.9)$$

Table 5.3 Performance evaluation using End-to-End Delay

Node Mobility(m/s)	End-to-End Delay (Sec)	
	MARMAQS	PNLP
10	6	15
20	6.2	16
30	7	18
40	8	19
50	9	20
60	9.2	22
70	9.4	23
80	10	25

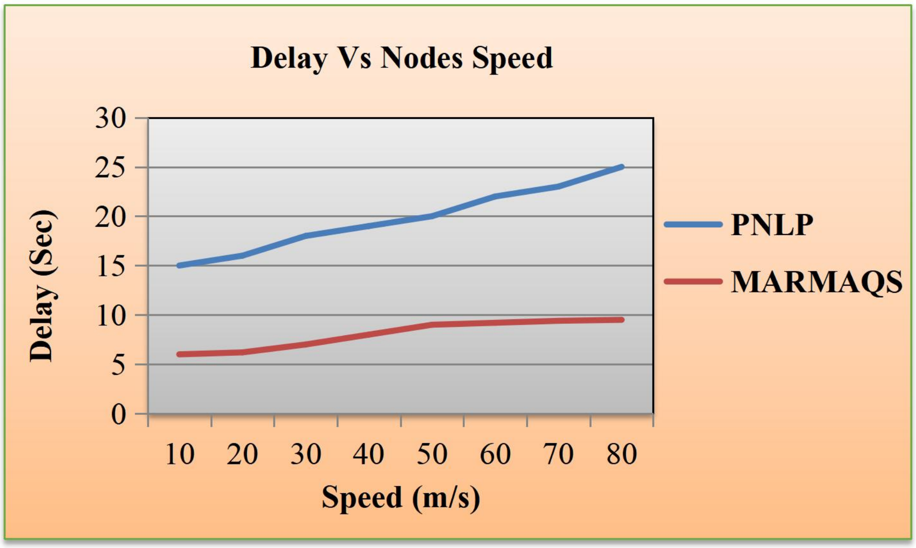


Figure 5.9 Performance of End-to-End Delay

As presented in both Table 5.3 and Figure 5.9,the outcomes of the performance evaluation reveal that MARMAQS outperforms PNLP in term of end-to-end delay for all the cases studied by varying the nodes speed. The proposed scheme maintains a lower delay ratiodue to the fact that it selects the best path with minimum hop-counts resulting in a short delay for a packet to reach the destination.

An interesting observation is that the delay ratios of both the protocolsalmost continually increases as each node speed is augmented.The main reason behind is that the destination node may be moving fast and going far away from the source node, resulting in an increase of the incurred delay in the network and some more time will be taken for a packet to reach the destination as some additional hops may appear in the network.

PACKET DELIVERY RATIO (PDR)

Packet Delivery Ratio isthe fraction of the number of delivered data packets to the destinationillustratingthe level of a packet delivery. The greater value of packet delivery ratio means the higher performance of the protocol.

$$PDR = \frac{\sum Number\ of\ data\ packet\ received}{\sum Number\ of\ data\ packet\ sent} \quad (5.10)$$

Table 5.4 Performance of Packet Delivery Ratio

Nodes Speed [(ms/s)]	Packet Delivery Ratio	
	MARMAQS	PNLP
10	0.1	0.5
20	0.2	0.4
30	0.4	0.1
40	0.6	0.3
50	0.5	0.3
60	0.4	0.2
70	0.3	0.1
80	0.2	0.1

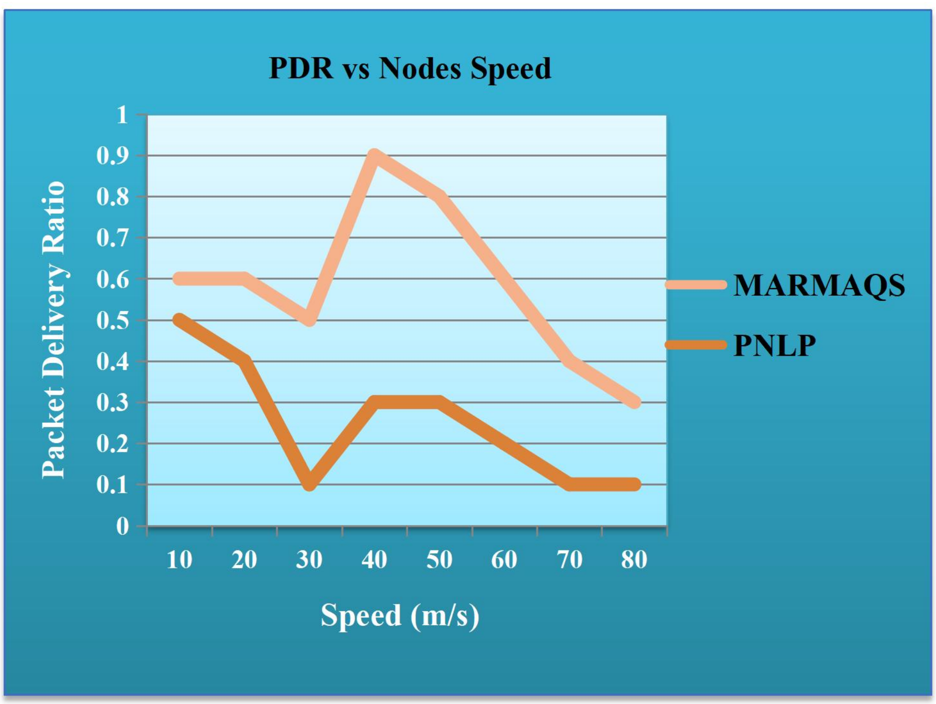


Figure 5.10 Performance of Packet Delivery Ratio

Table 5.4 and Figure 5.10 depict the outcomes of our simulation where MARMAQS is again compared with PNLP but this time in terms of Packet Delivery Ratio. The PDR of our proposed scheme remains higher than the PNLP's for the overall simulation time for small, medium, and high node mobility speed. The PDR for both protocols almost progressively decreases as nodes mobility speed increases, the main cause of this problem is the fact that the fraction of dropped packets increases caused by many factors such as congestion in the network with highly speedy nodes, or by frequent route failures and breaks which then results in minimized number of received packets at the receiver node.

THROUGHPUT

Throughput or network throughput is the rate of successful message delivery over a communication channel. In NS-2, it is defined as the total number of packets delivered over the total simulation time.

Table 5.5 Performance of Throughput

Number of nodes	Throughput [(Kb/s)]	
	MARMAQS	IRS
10	9	6
20	7	5
30	6.9	5.5
40	6.5	3.9
50	5.4	3.6
60	4	3.5

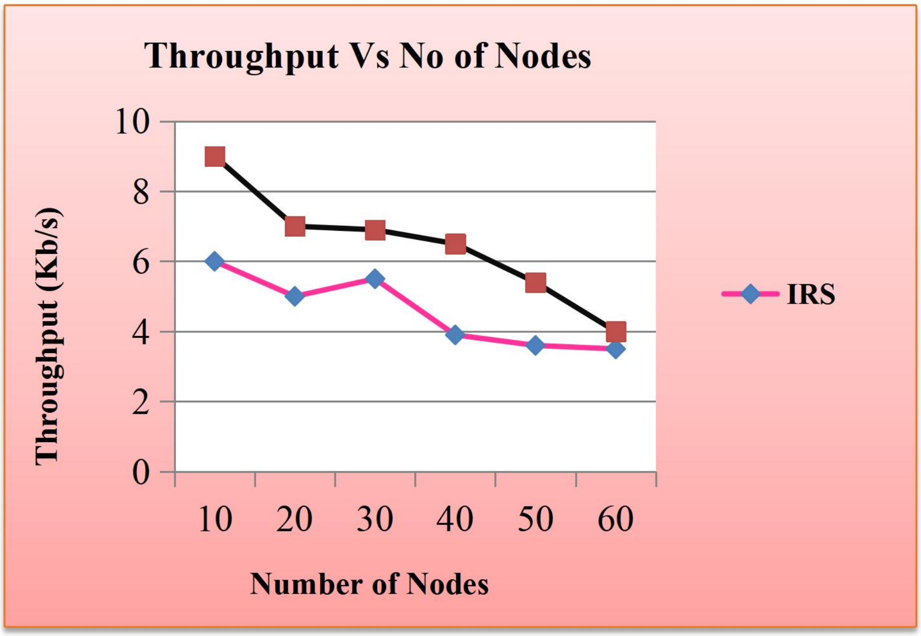


Figure 5.11 Performance of Throughput

As presented in Table 5.5 and Figure 5.11, the proposed scheme always exhibits a better behavior as it increases the throughput in the network maintaining its value higher than the IRS's for small, medium, and a larger number of mobile nodes. As the number of nodes increases, the throughput for both the protocols almost decreases due to the higher number of nodeswhich led to the increasing number of hops, resulting in a long transmission delay as the packets have to traverse various links and hops to reach the destination. Consequently, a drop in throughput ratio followed by the prolonged total transmission time occurs.

ROUTE RELIABILITY

Route reliability may be estimated based on various factors such as the node energy, security, etc. A reliable node may be the one robust to failures and secure. For achieving a high QoS provision rate, evaluating the route reliability is another approachwhich should be taken into consideration. For example, for security reasons, an intrusion detection system is used for testing the reliability of each path to pass packets through by gathering various information and identifying some security breaches involving both intrusions and the network misuses. A node along the path towards the destination node is identified as reliable as long as it does not exhibit any security breach to the network.Otherwise, it is classified as an intruder (unreliable) and an alternative path is then chosen. Routing reliability ratio may differ for various routing protocols.

The route reliability can be also estimated based on signal strength and nodes energy, for example, the route reliability can be calculated as follows:

Reliability Factor=RelCount / No. of Hops. (5.11)

Where*RelCount* is an extra field added to RREQ packet and contains the reliability count of the path it comes across.

As depicted in both Table 5.6 and Figure 5.12, as long as the route reliability is evaluated by varying the number of mobile nodes, the proposed algorithm's route reliability is maintained to a higher level when compared to the existing IRS's during the overall simulation time even when the number of nodes is increased, making the proposed protocol a better one. The best efficiency of the proposed algorithm relies on the intrusion detection mechanismwhich selects the best paths by avoiding the unreliable ones. Yet, the performance of both the protocols degrades as the number of nodes increases, and the main cause of such misbehavior is the proportional increase in the number of unreliable ones which further results in the overall route unreliability.

Table 5.6 Performance of Route Reliability

Number of Nodes	**Route Reliability**	
	MARMAQS	**IRS**
20	9	7
40	8	6
60	7	5
80	6	4
100	5	3

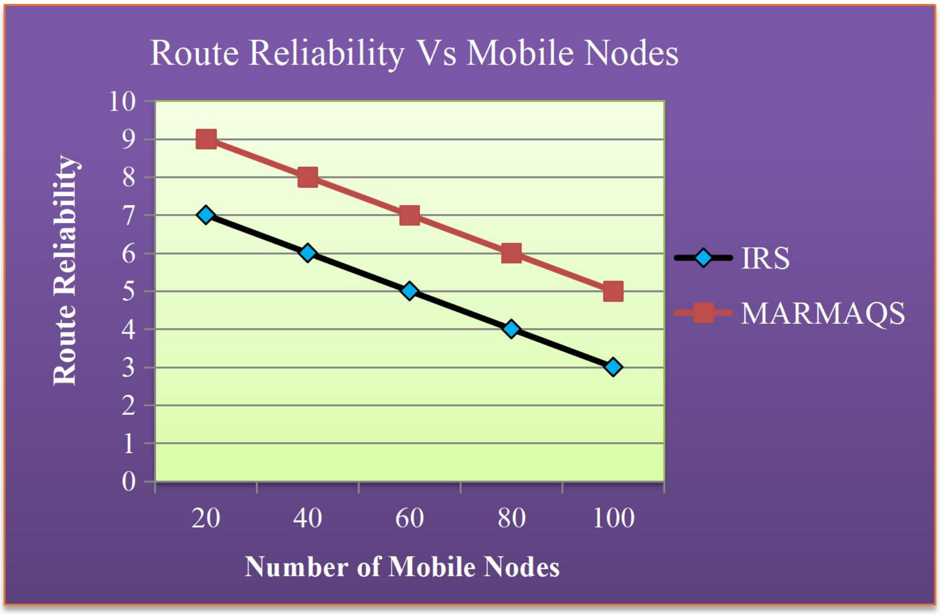


Figure 5.12 Performance of Route Reliability

ROUTING OVERHEAD

The routing overhead is a metadata and network routing information sent by an application. This transmitted information uses a portion of the available bandwidth of a communication channel. In MANETs, mobile nodes often change their location within the network resulting in the generation of some stale routes in the routing tablewhich further leads to unnecessary routing information transmissioncausing an increase of the routing overheadwhose ratio should be minimized.

Table 5.7 and Figure 5.13 present the outcomes of the performance evaluation using the routing overhead parameter while varying the velocity of nodes. The results revealed that the proposed scheme incurs lower overhead in the network even when the node velocity is augmented; it is possible because the proposed scheme limits the metadata and network routing information sent throughout the network. Interestingly, for both the protocols, the overhead ratio always depends on the dynamicity of node velocity as both the overhead and node velocities augment in the same fashion.

Table 5.7 Performance of Routing Overhead

Nodes Velocity (m/s)	Routing Overhead [(%)]	
	MARMAQS	LPR
5	50	62
10	53	64
15	55	66
20	60	70
25	65	80
30	71	81
35	72	84
40	75	88
45	78	90
50	79	95

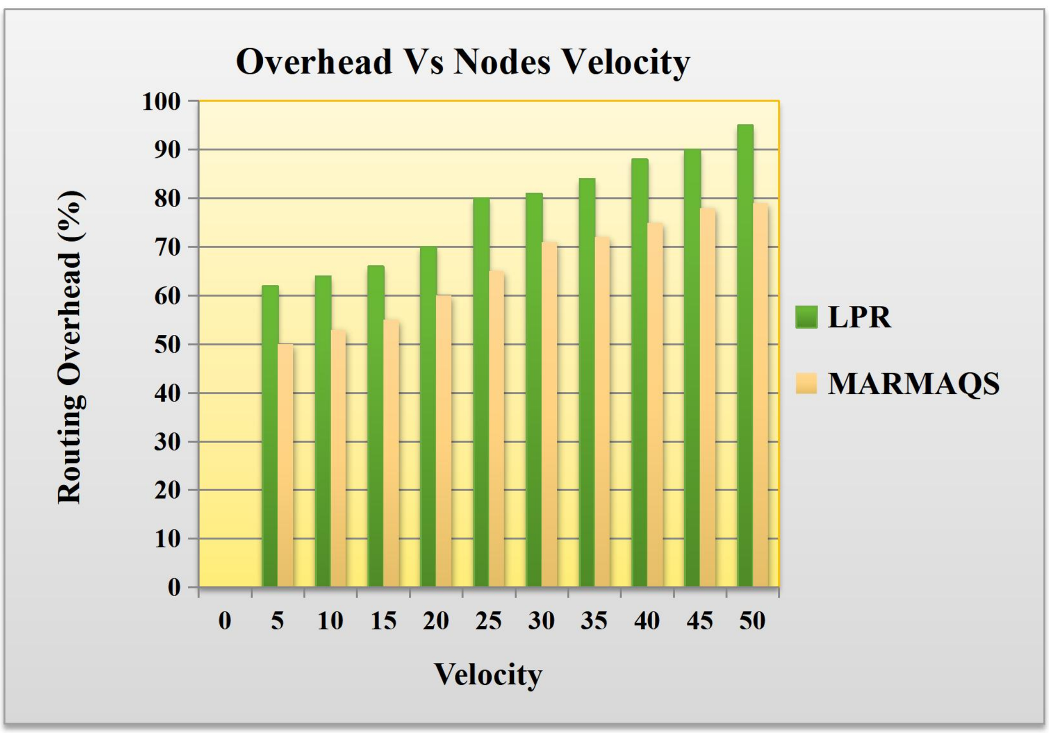


Figure 5.13 Performance of Routing Overhead

5.8 SUMMARY

MANET is a decentralized wireless network, providing high QoS (Quality of Service) in this type of network is still challengingespecially formultimedia applications. Several routing protocols have been designed mainlyaiming at providing high QoS but researchers have faced various challenges such asQuality of Service provision degradation caused by higher error rates and various constraints related to bandwidth, power, and applications. To provide a prominent solution to those negative issues, a new routing mechanism, MARMAQS (Multi-Algorithm Routing Mechanism for Acquiring high Quality of Service) has been proposed in this research work. The scheme isa mixture of three important QoS provision techniques namely the node and link lifetime prediction scheme, the packet scheduling approach, and the intrusion monitoring mechanism. The first technique, the Lifetime Prediction Routing algorithm consistsof route discovery, route selection, transmission process, and route maintenance operations.The second one, Urgency based Packet Scheduling (UPS) algorithmwhich performsthe packet scheduling operations by arranging them in an ordered manner before the transmission process starts uses the priority of both the packets and nodes based on the urgency calculation mechanism. The latter algorithm efficiently providesa security mechanism as it detects malicious nodes and avoids packet transmission at such mobile nodes. For performance evaluation of MARMAQS in comparison with the existing ones namely LPR, IRS, and PNLP, five different QoS parameters metricsi.e. End-to-End Delay, Packet Delivery Ratio, Reliability, Routing Overhead, and Throughput have been used while varying the number of nodes and node mobility speed. For all the studied cases, the simulation results confirmed that the proposed scheme (MARMAQS) outperformed the existing mechanisms as it providedhigher rates in terms of PDR, route reliability, and throughput with minimized routing overhead and end-to-end delay ratios. This achievement was possiblethanks to the mixture of various robust QoS routing algorithms into one protocol.

CHAPTER 6

FULL-FEATURED SECURE ROUTING CLUSTERING MECHANISM WITH ENERGY-AWARE AND SCHEDULING CAPABILITIES

The popularity of Mobile Ad hoc Networks has been recently increased due to the fact that the communication using mobile wireless devices is of various advantages compared to wired networks,especially for real-time applications. This type of wireless network consists of dynamically changing topology due to fast moving mobile nodes, each one freely moving and unexpectedly changing its own direction; this frequently leads to link changes and breakage in the network. Here, each node can be the sender, receiver, or a network router. Various challenges arise from the infrastructureless nature of MANETs such asQoS degradationwhich then results in the reduction of the whole networkperformance (Kaur (2015)).

Nowadays, there are various routing protocols proposed for MANETs.Many of those protocols perform well with small and medium-sized networks but become inefficient for large-scale MANETsas the proactive routing protocolsgenerate too much control traffics or would require too large routing tables for highly dense and large-sized networks. Regardless of the type of the protocol used, the information exchange between nodes in MANET is almost the same.

Data packets have to traverse various links and nodes to reach the destination. Hence, various problems consequently arise during this transmission such as the stolen, changed, or dropped packets due to both malicious nodes and route breakage events. The route breakage may be caused by dead or shutdown nodes due to their low battery powers or some mobile nodes getting out of the range due to their fast moving speed.

Though the ad hoc networks are widely used, they still have some vulnerabilities in them. For example, some nodes maybe under attacks and exhibit an anomalous behavior called the malicious behavior. In this situation, the entire operation of a network gets disturbed. An intruder utilizes this vulnerability to know about the network processes and then attack the network.

A major problem with MANET is related to dynamic and unpartitioned large-sized networkwhich makes the network hard-manageable. Another problem is related to routing issueswhere some protocols do not take care of an end-to-end fairness in MANETs.Thereforea scheduling scheme is required but for years, this issue has not been addressed effectively. All those previously mentioned negative issues frequently lead to the performance and scalability problemsespecially when the network size increases.

To circumvent all those performance-related problems, the clustering techniqueis taken into consideration and a new mechanismis proposedin this research work.Full-Featured Secure Routing Clustering Algorithm with Energy-Aware and Scheduling capabilities for highly increasing QoS in MANET (FSR-CAES)which combines different algorithm, each one providing a dedicated solution to the corresponding problem previously mentioned.

The entire network is first divided into small and manageable areas (clusters). Mobile nodes will elect a cluster head, a node with the high processing speed and energy compared to other nodes in the same cluster. Those cluster heads play a major role inco-coordinating other nodes in the clustered architecture by performing the role of the local coordinator and achieving transmissions in both the intra- and inter-cluster arrangements**.**

The performance of our proposed scheme is enhanced by adding some advanced features to contain all the previously mentioned problems in order to increase the QoS.The malicious node detection technique mainly aimsat detecting and preventing malicious nodes from launching gray hole/collaborative black hole attacks in MANETs (Chang et al. (2015)).

Mobility and distance-based packet transmission technique is used to select the best short route by implementing the node mobility and distance measurement schemes using the random walk with wrapping mobility model. Route discovery and packets scheduling techniques during the transmission processes arealso used to achievesuccessful transmission processes, and finally, the power-aware routing features efficient in preventing the unexpected shutdown of any node arealso taken into consideration in the proposed scheme.

6.1CLUSTERING IN MANET

6.1.1 Clustering

The clustering technique consists of dividing the network into different virtual groups based on rules in order to discriminate between the nodes allocated to different sub-networks. The interconnected substructures are known as clustersandall the mobile nodes are grouped into different geographically distributed groups. Clustered networks guarantee numerous advantages compared to traditional networks but due to the unstable nature of MANETs, performing this kind of operation is sometimes a difficult task.

Dividing the network into clusters provides various advantages such as enabling the cluster head to record paths between clusters instead of between nodes which then results in the increase of both the route lifetime and network capacity, thus, decreasing the routing control overhead. Other nodes in a group will communicate with the cluster head inspite of their mates. The cluster head in a group may communicate with another cluster head leading the adjacent cluster through the gateway node, thereby decreasing the unnecessary traffic flows (Uikey (2013)).

6.1.2 Motivations behind Clustering Algorithms

Cluster-Based Routing Protocols (CBRP) can be used for enhancing the routing performance in MANETs. A CBRP has the following features:

- It provides a fully scattered operation.
- It reduces the flooding traffics.
- It locally repairs the broken routes.
- It mitigates the topology changes in Mobile Ad hoc Networks.
- It stabilizes the end-to-end communication paths and maximizes the path lifetime.
- It also improves the network scalability such that the routing overhead does not become tremendous in large-scale ad hoc networks (Jiang andLi and Tay (1999)).

6.1.3 Terms used in clustering

In a cluster structure, mobile nodes may be assigned a different working mode and functionsand can be nominated as the cluster head, ordinary node, gateway, or cluster members.

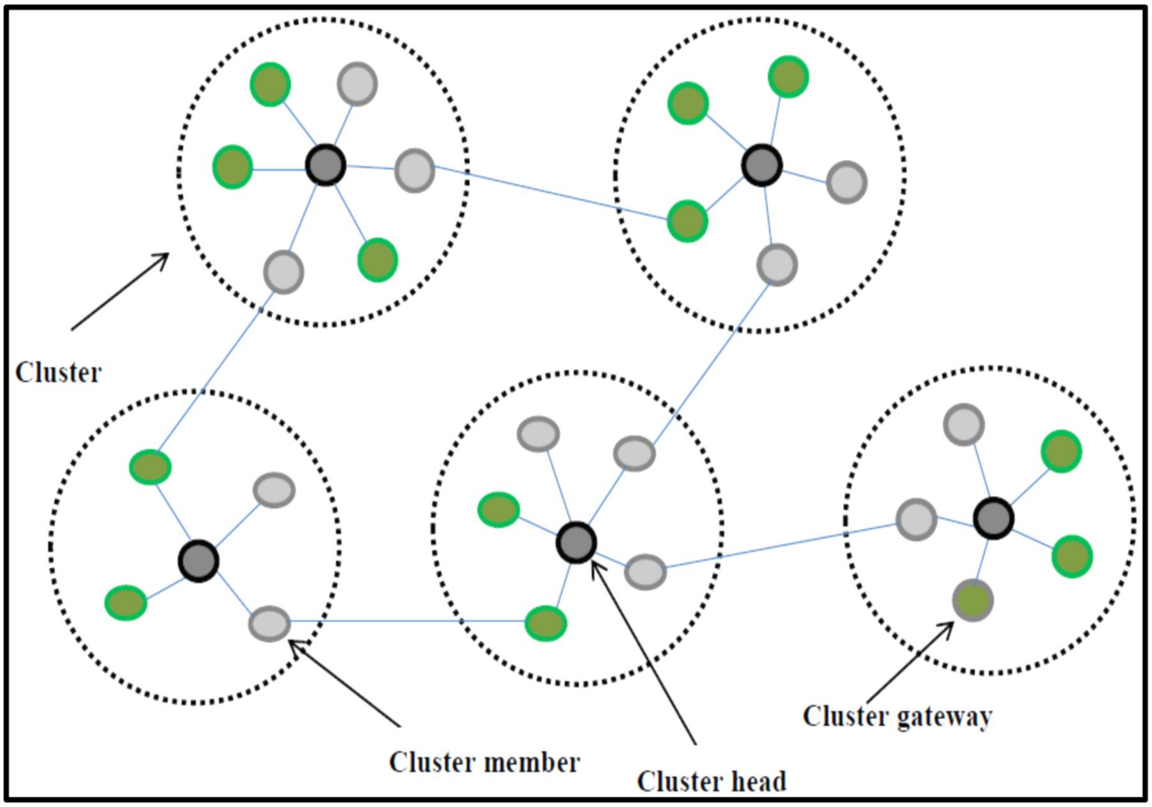


Figure 6.1 *C*luster structure in MANETs

- ✓ *Cluster head* – This is a node having the highest residual energy estimated while exchanging a HELLO message, has created a cluster for which it was nominated the head and whose mobility is either low or medium.
- ✓ *Cluster member* – Ordinary node, which is neither a cluster head nor a gateway node. Each node belongs exclusively to a cluster independently of its neighbors that must reside in a different cluster.
- ✓ *Cluster gateway* – Gateway nodes are at the border of the cluster, they transfer the information from one cluster to another. A border node is a mobile node having at least one neighbor belonging to a neighbor cluster.
- ✓ *Cluster guests* – A node associated with a cluster.

6.1.4 Advantages of clustering in MANETs

Clustering approach helps to improve the performance of large and dense Ad Hoc networks. The overall benefits of clustering techniques in MANETS are as follows:

- *Aggregation of Topology Information:* Due to the fact that the number of nodes of a cluster is lower than the number of nodes in the whole network, the clustering process assists in aggregating topological information.
- *Improve the Routing Efficiency:* In flat topology, every node bears an equal responsibility to act as a router for routing the packets to every other node, so a great amount of flooding messages takes place in order to obtain better routing efficiency. Yet, such control packets reduce MAC layer efficiency.
- *Bandwidth Efficiency:* Only the cluster heads participate in the routing processes and the cluster members interact only with their cluster headsaiding in avoiding the unnecessary exchange of messages among the mobile nodes.Thus, the utilization of bandwidth can be improved.
- *Efficiency and Stability:* The significant feature of the cluster structure is that it causes MANET to seem smaller and more stable. For instance, when a mobile node switches its attaching cluster, only nodes residing in the corresponding clusters are required to modify their routing tables.
- *Resource Management:* In a cluster structure, each node is assigned different role and functionality. Each cluster is assigned a cluster head and if a node comes within the transmission range of more than one cluster, it will be acting as a gateway node. Therefore, in this way, the cluster topology facilitates resource management **(**Aruna and Subramani (2014)).

6.1.5 Classification of Clustering Algorithms

Clustering algorithms in MANETs can be classified based on different criteria. In this work, the clustering protocolsare classified based on their objectives. According to this criterion, clustering algorithms are classified into four categories namelymobility-based clustering algorithms, energy-based clustering algorithms, connectivity-based clustering algorithms, and weighted clustering algorithms **(**Savyanavar et al. (2014)).

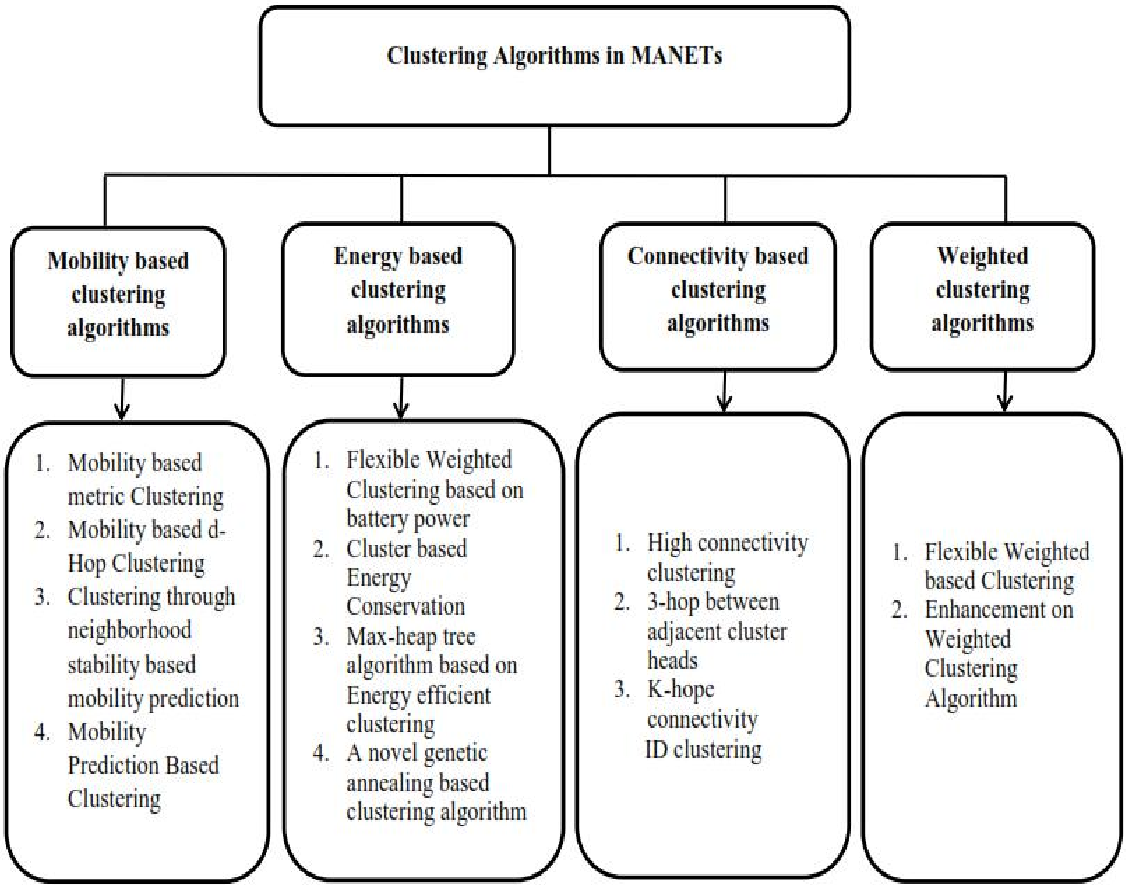


Figure 6.2 Classification of Clustering Algorithms

6.2DEFINITION OFTHE PROBLEM

Various categories of routing protocols face different challenges during the overall operations of MANETs. These protocols present some strengths and weaknesses depending upon the operations being performed. For example, proactive routing protocolswhich keep the information about each and every link/node in the form of the routing table generate a large number of control packetswhich continually circulate in the network, thus, consuming the bandwidth and energy. Consequently, a drop in both the bandwidth and successful delivery of various normal packets occurs.Thus, a large routing overhead is generatedwhich significantly affectsthe whole network performance as the QoS is highly degraded by these types of events.

To alleviate all those problems, the clustering technique should be usedwhich is efficient in hierarchical routing by grouping geographically close nodes. Each group, known as a cluster, is represented and managed by a particular node called a cluster head; a node elected among the others based on some QoS-based criteria. This techniquewhich is very advantageous in managing large-scale MANETs should be incorporated in each protocol designing processes by various researchers.

The scalability of the network is also affected most importantly when the network size increases. Another problem arises when the MANET topology consists of low-capacity deviceswhich are unable to handle the large storage requirements of every route to every node in large and dynamic networks. Power constraints have not to be neglected as the operations of MANETs are regularly constrained by the limited battery power lifetime; this issue makes a node's active state short due to unrealistic shutdown or restart. This tragic event affects the reliable data transmission operations from one end to another, thus, resulting in the Quality of Service degradation in the whole network.

The problem of malicious nodes is also crucial in MANETswhich are unwanted nodes regularly disguising themselves and acting as normal nodes in the network and often causing the security breaches into the network as they may steal some packets transmitted throughout the network or may cause some additional problems during the transmission processes.

The mobility of nodes is another important issue which retards MANET performance; it affects the number of average connected pathswhich in turn affects the performance of the routing algorithm. While the source node is in the process of finding the path to route packets through, it should consider the node mobility as one of the selection criteria as a selected node with high mobility will easily fall out of the transmission range and cause both path failure and breakage. Various inefficient routing protocols do not take into account this frequent problem, thus, regularly decreasing MANET’s overall performance.

Another important problem is concerned with the scheduling of packets before the transmission process begins.A decision should be made for selecting the packets to be serviced or dropped; it manages the sequence of the network packets in transit. The packet scheduling technique is very important in maximizing the system capacity while satisfying the user requirements and achieving a certain level of fairness. Despite the importance of this scheme, it is not often taken into consideration by various protocol designers

6.3 METHODOLOGY

6.3.1Proposed Algorithm

As a prominent solution to the previously mentioned MANET-related problems, a new robust algorithm; Full-Featured Secure Routing Clustering Algorithm with Energy-Aware and Scheduling capabilities for highly increasing QoS in MANET (FSR-CAES)is proposed in this work. The proposed scheme proves to be an efficient clustering techniquewhich consistsof numerous algorithms, each one containing one of those negative issues affecting the whole network performance. Being a multipurpose protocol, FSR-CAES isvery effective in increasing the Quality of Service in MANETs.

The proposed mechanism is implemented in the following steps:

(1) Cluster formation,
(2) Cluster head and gateway node selection,
(3) Malicious node detection using RREQ,
(4) Mobility and distance measurement for packet transmission purposes,
(5) Scheduling based on an optimal threshold, node and route urgency and
(6) Routing.

6.3.2 Cluster Formation

The cluster formation process happened in such a way that the network is divided into different groups of nodes, each one forming a cluster. The main purpose of the approach isto reduce the transfer rate and allocate each node to a cluster so that the transmission between them iseasier. Each node can be one of the three types: common node or normal node, cluster head node, or the gateway node (Kumar and Chaturvedi (2011)).

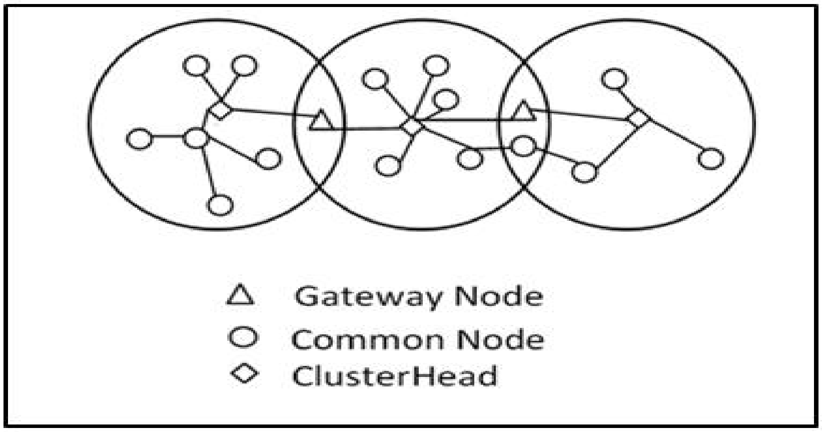


Figure 6.3 Cluster formation in MANETs

Mobile nodes in the cluster canbe in one of the following modes:

- **Cluster head**: isa nodewhich isa representative of each subdomain (cluster) and whose energy ishigh and mobility is either low or medium. It playsa major role as a local coordinator by performing intra- and inter-cluster operations.
- **Common/normal node:** It is the node after the HELLO message exchange process has been completed.Its residual energy is less compared to its neighbor nodes andit is part of the cluster members.
- **Undecided Node:** This isthe mode of a node which hasjust arrived, or hasleft its cluster and currently hasno neighbor node in its neighborhood. It is the startup mode of each node, its status is not yet decided as it is still waiting for HELLO messages to come.
- **Gateway Node**: Gateway nodes are at the border of the cluster, they transferinformation from one cluster to another. A border node is a mobile nodewhich has at least one neighbor belonging to a neighbor cluster.

6.3.3 Size of the Cluster

Size of the cluster isthe total number of nodes composing each cluster i.e. the Cluster-Head *(N_{ch}),* Gateway node *(N_{gw}),* and Common nodes *(N_c).* The common nodes arethe normal nodes belonging to a clusterwhich do not play a major role in routing decisions and do not participate in operations involving the communication between clusters. The gateway node is located at the border of the cluster to relay information from one cluster to the adjacent one. *ClusterSize (CS)* can be defined by:

$CS = \frac{N_{ch}+N_c}{N_{ch}}$ (6.1)

$N_{ng}=N_{nch}-1$ (6.2)

where

N_{ng} is the number of gateway nodes

n_{ch} is the number of cluster-heads in the network

n_c is the number of common nodes.

6.3.4 States of Nodes

Each node present in the cluster canbe in one of the following three states:

Transmitting State:

When a node in the cluster istransmitting messages with the power of transmission*P_tx*.

Receiving State:

When a node is receiving a message with a power of reception*P_rcv*.

Idle state:

The nodewhich remains idle and keeps listening to the traffic events in the medium with *P_idle*i.e. no message being transmitted or received by the node. The previous states depict how the battery energy is consumed by nodes depending on their current status. The transmission operations consumemore energy than the receiving ones but a node in an idle state also spent some energywhich ismuch lower than that consumed during the receiving processes.

Therefore,

$$P\_tx > P\_rcv > P\_idle.$$

Both the node residual energy and mobility are the indices to either increase or decrease the number of the cluster heads and maximize the whole network lifetime. For example, the energy of the i^{th} node isdecreased when it startstransmitting or receiving some packets. The energy consumption estimation at each node can be measured according to the following conditions:

When the node *i*starts the packet transmission process:

Transmitting Energy $REitx(\Delta t)=P\_tx * txtime$ (6.3)

When the node *i*receives a packet:

Receiving Energy $REircv(\Delta t)=P\_rcv * rcvtime$ (6.4)

When the node *I* is in the idle state:

Idle Energy $REiidl(\Delta t)=P\_idle * idletime$ (6.5)

During Δt period of time, Total Energy is:

$REitot(\Delta t)=REitx(\Delta t)+REircv(\Delta t)+ REiidl(\Delta t)$ (6.6)

Residual energy $REi(t) = REi(t-\Delta t) - REitotal\ (\Delta t)$ (6.7)

Where*txtime* isthe packet transmission time, *rcvtime* is the packet reception time, *idletime* is the time during which the node isin the idle state, *REi(t)* isthe residual energy at any point of time *t.REi(t-Δt)* is the total residual energy at *t-Δt,REitotal (Δt)* isthe total energy consumed during the time of interval *[t-Δt, t]*and *Δt*is a clustering interval of timewhich represents each node'srestarting processes.

6.3.5 Selection of Cluster Head and Gateway Nodes

A cluster head node plays a vital role in the network as its inherent role is to coordinate the cluster members and collaborate with other neighboring cluster heads in the same network, thus, playing the role of a local coordinator as it performs intra- and inter-cluster operations.It also acts as a base station for all the other cluster members. Selecting a cluster head is not an easy task as it is elected depending on various factors such asmobility of the node, stability, capacity, energy, throughput, its trust value, node ID, and the geographical location of the node. Cluster head selection criteria may vary based on the network nature (Sruthi and Umamakeswari (2014)). In this research work, the cluster headis electedbased on the residual energy of the nodewhich is calculated using the node's received hello messages.

The following is the procedure adopted for cluster head and gateway node selection:

Δt isthe clustering intervalwhere the restarting process of the criteria calculation for each node occurred. *REi* is the residual energy of each node while *RE=Max(REi).* The residual energy isperiodically calculated by the node using the *HELLO* message received which makesthe node to be aware of thecondition it hasto fulfill to pass from one mode to another.

*Step 1:*If the node isin the startup mode for a period of time *Δt* or has just arrived and after another period of time it doesn't receive any intimating *HELLO* message, then it is implied thatthere isno neighbor, hence, it will immediately move to Undecided Node mode.

Step 2: If $(RE_i \geq RE)$ istrue. The node *i*changesits mode from undecided to Cluster-Head and will go back to undecided mode once it receives no *HELLO* message after a period of time *Δt,* the time after which it isinitialized.

Step 3: If $(RE_i < RE)$ is true. The node *i* changes its mode from undecided to thecommon node. It will be initialized at the time*Δt* if no *HELLO* message has been received after this period, it decides to move back to undecided node mode.

Step 4: If the node is in common node mode and satisfiesthe condition at *Step 2,* then it will move to Cluster-Head mode.

Step 5: If the node*i* is in common node mode and satisfies the condition at *Step 3* then it has not to change its mode.

The cluster's gateway isa border node used to convey the routing information from one cluster to another. The cluster head and gateway nodes form the backbone network. The gateway nodes areselected among the border nodesandhaveat least one neighbor belonging to a different cluster. Border nodes areat the perimeter of the clusters. Gateway nodes are those nodes in a non-cluster head state located at the periphery of a cluster. They are involved in the transmission to or from a node belonging to a different cluster;hence, ithas to have at least one neighbor node belonging to a different cluster.

Two types of data tables available at each node are:

- Neighbor node table
- Cluster adjacency table.

Table 6.1 Neighbor Node Table

Neighbor nodes Id	**Neighbor node mode**	**Next node along the path toward the neighbor node**	**Hop-count to the neighbor**

Neighbor node Table (NTAB) maintains the neighbor node Id, neighbor node mode, the next node along the path towards the neighbor node andthe hop-count to the neighbor.

Table 6.2 Cluster Adjacency Table

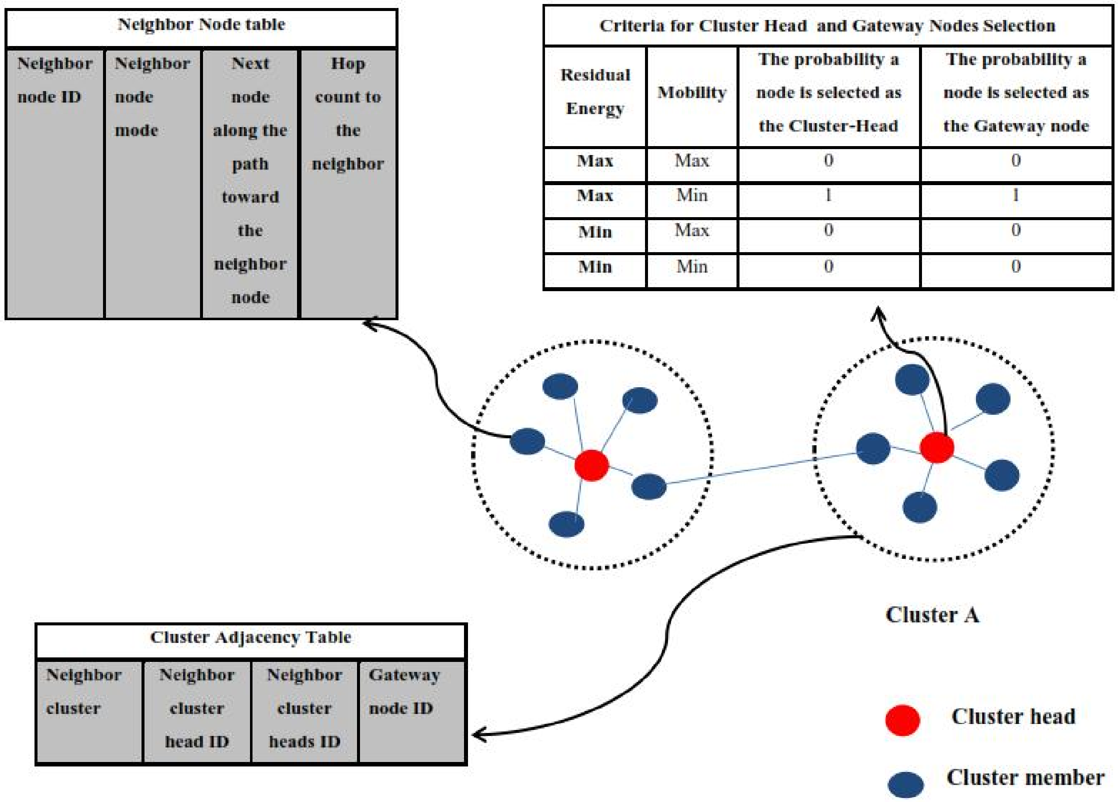
Neighbor cluster	Neighbor cluster head Id	Gateway node Id

The Cluster Adjacency Table (CATAB) maintains the information about the adjacent cluster such asneighbor cluster, neighbor cluster head Id, and gateway node Id.

Step 6: The border nodewhich containsthe information about the neighbor node Id located in the neighboring cluster and maintaining both its NTAB and CATAB isselected as the gateway node.

Table 6.3 Criteria for cluster head and gateway node selections

Residual Energy	Mobility	The probability a node is selected as the cluster head	The probability a node is selected as the gateway node
Max	Max	0	0
Max	Min	1	1
Min	Max	0	0
Min	Min	0	0



Neighbor Node table			
Neighbor node ID	Neighbor node mode	Next node along the path toward the neighbor node	Hop count to the neighbor

Criteria for Cluster Head and Gateway Nodes Selection			
Residual Energy	Mobility	The probability a node is selected as the Cluster-Head	The probability a node is selected as the Gateway node
Max	Max	0	0
Max	Min	1	1
Min	Max	0	0
Min	Min	0	0

Cluster Adjacency Table			
Neighbor cluster	Neighbor cluster head ID	Neighbor cluster heads ID	Gateway node ID

Figure 6.4 Proposed framework for clustering in MANETs

BEGIN

C: Number of clusters in the area

CS: Number of nodes in a cluster

NnCH: Number of Cluster-Heads in the network

NnG: Number of Gateway nodes in the network

E: Residual Energy

M: Mobility of a node

Send RREQ, Receive RREP

Nodes update their NTAB and CATAB

Find E, M

i=1

While (NnCH<=C)

Check whether the node i in the ith network satisfies either Step 2 or Step 4 conditions

If Yes

Select the node i as the NiCH in the i^{th} network

NnCH = NnCH +1 // Add one Cluster-Head to NnCH

Otherwise

Check whether the node i in the i^{th} network satisfies the Step 6 condition

If Yes

Select the node i as the NG in the i^{th} network

NnG = NnG +1 // Add one Gateway node to NnG

Otherwise

i=i+1 /* Check for both the Cluster-Head and Gateway nodes in the next network */

End If

End If

End while

END

Figure 6.5 Cluster head and gateway nodes selection processes

Upon completing this cluster formation process, the source node sends an RREQ control message to other nodes in the cluster. It caneither send the request to all other nodes in the cluster or to its cluster head. In the second case, the cluster head checksthe destination Id of the request to be sure whether this node ispresent in its cluster.If so, the sender caneasily reach the destination node and immediately start transmitting the packet, otherwise, the cluster head will forward the request to the neighboring cluster head via the gateway node. The process continues until the packet reachesthe destination. The cluster head node hasanother important responsibility; finding some malicious nodeswhich could cause security breaches into the networkthanks to the Bait RREQ request.When found, it sends the information about the malicious node to its own cluster members as well as to the neighbor cluster head.

6. 3.6 Random Walk with Wrapping Mobility Model

Mobility model is mainly designed for describingmovements of mobile nodes and analyses the results such as theirspeed and directions over time. Currently, there are two types of mobility models in MANETs namely the trace-based model and synthetic-based model. Based on the movement of a node, mobility models are classified into three categories; random waypoint mobility model, random walk with wrapping mobility model, and the random walk with reflection mobility model. In this research work, the random walk with wrapping mobility model is used for identifying node movements and their positions over time (Gowrishankar et al. (2010)). The mobility model is a perfect simulation model because it does not have a transient time. A tripwhich combines duration at any given point of time T_n with a position P_n will have a trip duration of $S_n \in R_+$. The next transition time for a mobile node is given by $T_{n+1}=T_n+S_0$ with a position of

$P_n = \left(\frac{t-T_n}{S_N}\right)$(6.8)

*Vn*is the speed at which a node moves. Upon reaching the end of a boundary *(x0, a2),* the node wraps to the other endat a location of *(x0, 0)*. If $R2 \rightarrow A$ is the wrapping function, then

$\begin{pmatrix} x \\ y \end{pmatrix} \rightarrow b\begin{pmatrix} x \\ y \end{pmatrix} = \begin{pmatrix} x \bmod a_1 \\ y \bmod a_2 \end{pmatrix}$(6.9)

6.3.7Mobility and Distance-Based Packet Transmission

With the proposed scheme, when a node needs to send out a packet, it has to check whether any route is available through which the packet will pass to reach the destination. The cluster, cluster head, and gateway formation operations are performed based on each node's residual energy, its mobility, and the distance at which the node is currently located from the source node (Gowrishankar et al. (2010)).

6.3.8 Malicious Node Detection Using RREQ

Various researchers have investigated malicious node detection schemes in MANETs. Most of these solutions only deal with the detection of a single detection scheme or require enormous resources in terms of time and cost for detecting cooperative black hole attacks. Furthermore, these methods necessitate some specific requirements to solve these kinds of problems in MANETs. Different detection schemes were proposed by various researchers such asproactive and reactive detection (Olushola and Babu (2015)).

A Cooperative Bait Detection Scheme (CBDS)which mainly aims at detecting and preventing malicious nodes from launching gray hole/collaborative black hole attacks in MANETswas introduced. With this technique, the source node chooses an adjacent node and uses it as a bait destination addressthe malicious node will be detected and caught when it sends back a suspicious RREP message to the sender. The reverse tracing technique is then used to both detect and disallow any malicious node from participating in the routing operations. This mechanism combines both proactive detection from the source node and a reactive response at the subsequent steps in order to reduce the resource wastage. With this scenario, the source node is able to identify all the nodes located on the selected path towards the destination. However, it is not always the case as sometimes for the source node, it may not be always necessary to be able to identify which intermediate node has the information to the destination, has an RREP message, or is the malicious one.

In this case, the source node may send its packets along the chosen fake shortest path which then results in a black hole attack occurrence. To solve this issue, CBDS algorithm is enhanced by extending it with an additional feature i.e. the function with a HELLO messagewhich is efficient in helping each node to identify adjacent nodes located in one hop by proactively sending a bait message having the bait address to entice the malicious node, a reverse tracing program is then used to detect their exact locations. The destination addresses are used as the bait addresses.

Table 6.4 Bait RREQ Packet Format

<table>
<tr><th>Option Type</th><th>Opt. data Length</th><th>Request ID</th></tr>
<tr><td colspan="3">Target address (RREQ’: Bait address)</td></tr>
<tr><td colspan="3">Address[1]</td></tr>
<tr><td colspan="3">Address[2]</td></tr>
<tr><td colspan="3">…</td></tr>
<tr><td colspan="3">Address[n]</td></tr>
</table>

Table 6.5 Hello Message Format

Node ID	**Node Status**	
Neighbor ID	Neighbor Status	Link Status
………	…..	
Adjacent cluster ID	……	
……….		

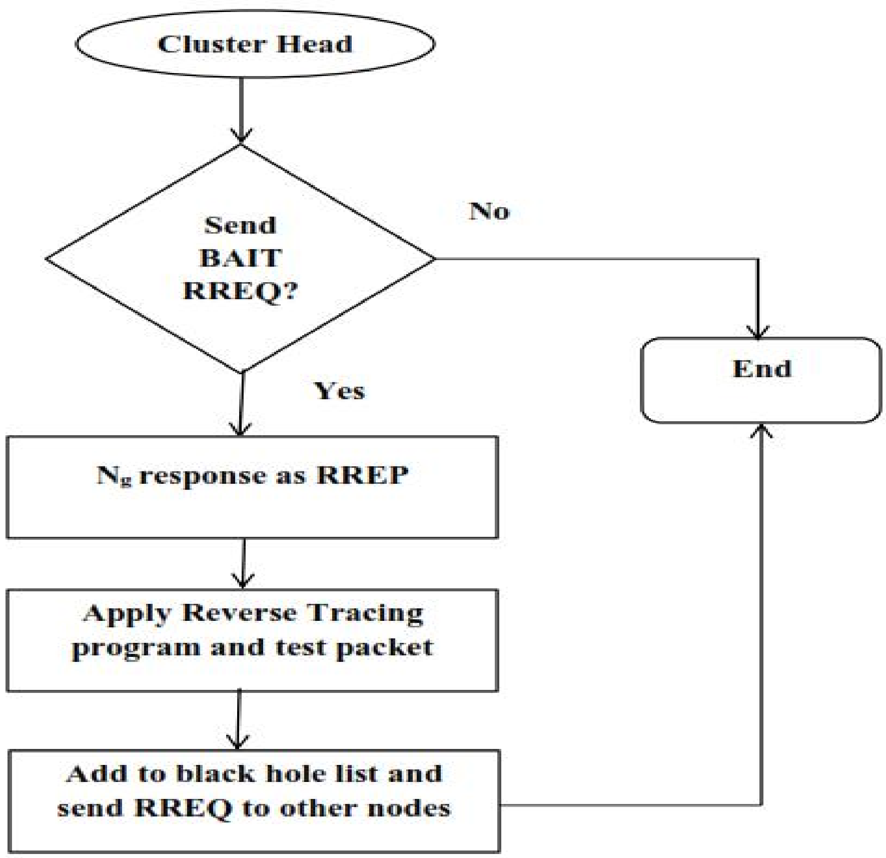


Figure 6.6 Malicious node detection

6.3.9 Mobility Measurement analytical model

Mobility measurement in term of time derivatives of remoteness is calculated as follows:

$$M(t) = \frac{1}{N}\sum_{i=0}^{N-1} M_i(t) (6.10)$$

Where N is the number of nodes

$$(t) = \frac{1}{N-1}\sum_{j=0}^{N-1} \left|\frac{d}{dt}F\big(d_{ij}(t)\big)\right| (6.11)$$

$M_i(t)$ is a measure of other nodes relative movements as observed by the node *i*.

$F(d_{ij}(t))$ is the movement of a node from a location *i* to the new location *j* where $d_{ij}(t)$ *is* $|n_j(t)-n_i(t)|$.

Let $n_i(t)$ be the location vector of the node *i* at the time *t* where $i=0,1,2,..,N-1$ and $M(t)$ represents an average amount of the movement of a node in the network at the time *t*, in a steady state, the following equation holds:

$$M = \frac{1}{T}\int_0^T M(t)dt \quad (6.12)$$

If a node is in the vicinity of the communication range, node remoteness will change dramatically as the node moves in or moves away. In the light of these observations, it must be ensured that *F(.)* defined by Kwak et al. (2003) satisfies the following:

From the gamma cumulative distribution *(CDF)* function with $\lambda=(r-1)/R$:

$$F(x) = \frac{1}{\tau\Gamma(r)}\int_0^x \lambda e^{-\lambda\tau}(\lambda\tau)^{r-1}d\tau \quad x \geq 0, r \geq 2 \quad (6.13)$$

If *F(.) is* used, then, equation 6.11 becomes:

$$M_i(t) = \frac{1}{N-1}\sum_{j=0}^{N-1} \left|d'_{ij}(t). f d_{ij}(t)\right| (6.14)$$

Where *F(.)* is the gamma probability density function *(pdf)*. *M (t)* is suitable for multi-hop network applications.

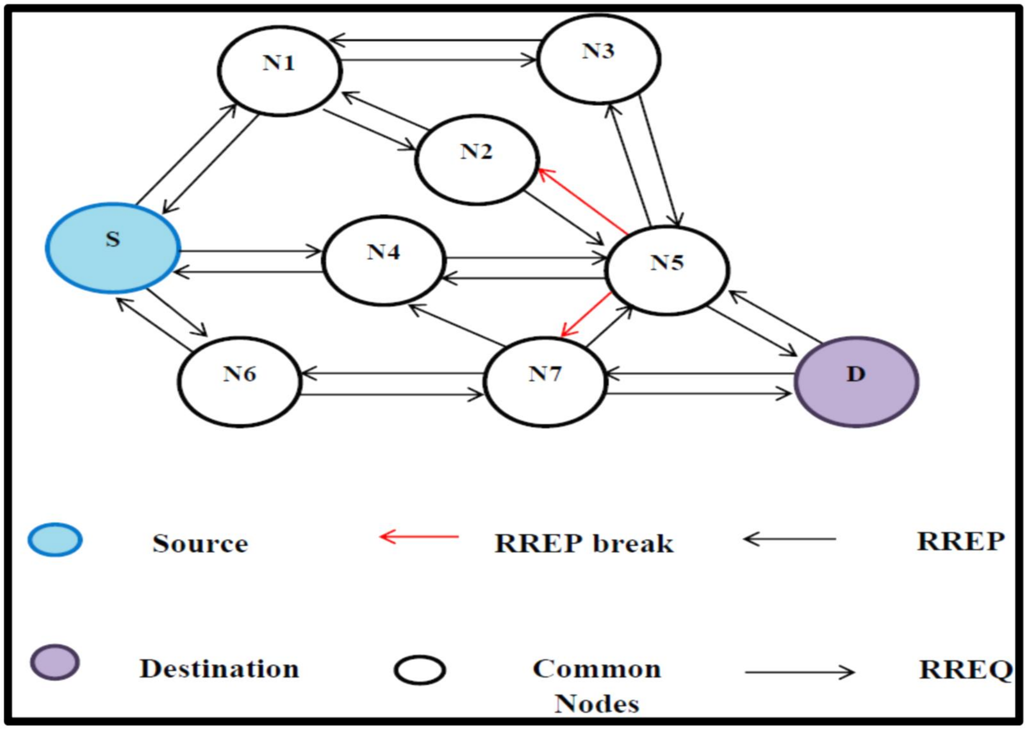


Figure 6.7RREQ/RREP packet transmission in a cluster

6.3.10 Distance Calculation

The following example shows how a distance between the source node and the destination node can be calculated. Let *S* be the source node and *D*be the destination nodeand the transmission range of each node be 250meters. It is better to select a route with the minimum hop-count among the possible paths to reach the destination:

S→N1→N3→D, S→N1→N2→N3→D, S→N4→N2→N3→D, S→N4→N5→D, S→N6→N7→N5→D, S→N6→N7→D, S→N7→D.

Here, a path with minimum hop-count is selected for the packet transmission purpose:

S→N7→ D

A problem may arise, for example when *N7* moves out of the path toward the destination, it immediately falls out of the transmission range of *S,* this further leads to RREP break, making this path useless; this is a big problem as other pathways were previously discarded when this path was selected (first RREQ). The routing table is used to store all the routing information.

To select an appropriate node to participate in the best path selection process, parameters such as distance and residual energy are used. The velocity of the node i, for example, is calculated when it moves from the i^{th}place to j^{th}place. To prolong the route overall lifetime, the distance between the two nodes say *i* and *j*will be used. Hence, the normal distance *(M_{ij})* is calculated using D_{ij}; the distance between these two nodes and *Transi* is the transmission range of the node *i*.

$$M_{ij}=\frac{D_{ij}}{Trans_i}\quad(6.15)$$

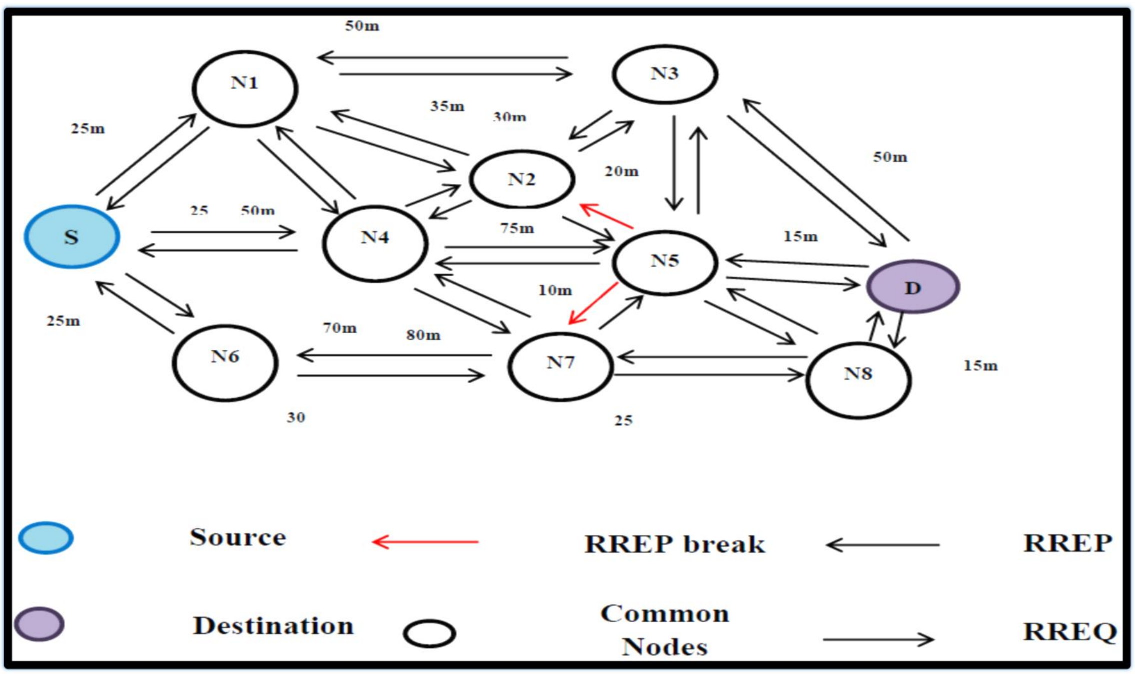


Figure 6.8 Distance between nodes in the cluster

Table 6.6 Format of an RREQ message**Table 6.7** Format of an RREP message

RREQ message
Source IP Address
Source Sequence Number
Broadcast
Destination IP Address
Destination Sequence Number
Next hop ID
Hop-count
Entry Expiration Time

RREP message
Destination IP Address
Destination Sequence Number
Hop-count
Source list:{(nexthop_IP1: hop_count1), (nexthop_IP2:hop_count2)….(nexthop_IPn: hop_countn)}
Entry Expiration Time
Distance

The location-based routing method is used for large and highly dense networks to find out the location ofthe participating nodes. RREQ contains all the information about allthe possible routes towards the destination namelyDestination IP, Destination Sequence Number, Next Hop ID, Hop-count, Entry Expiration Time, and Distance, while the RREP message contains the Destination IP, Destination Sequence Number, Advertised Hop-count, andSource List (Next Hop_IP, Hop-Count, Entry Expiration Time, and Distance).

When an RREP message is received from a node say Node *3*, it will select the intermediate nodes to pass packets through towards the source node based on Distance, Mobility, and Energy parameters. Using the equation: $AC2{=}AB^2{+}BC^2$ (6.16), based on the distance, some nodes are neglected, the process is performed as follows: all possible routes are initially selected, the final distance is calculated, then, the shortest path is selected and the transmission is started on it by neglecting the other longer paths.

6.3.11Route Discovery Process

The route discovery process is necessary for the first time when a sender node needs to initiate the transmission process of a packet and selects the best alternative path when the current route to the destination fails or breaks. For both the cases, the selected paths must be able to extend the route's overall lifetime based on the distance between the neighboring nodes and their respective velocities. During this process, the sender initiates the route discovery process by broadcasting the RREQ. The Entry Expiration Time; apart from the RREQ packet allows maintaining the route for some period of time. When a route breakage occurs, the source node updates its routing table, resends the RREQ for initiating the recovery process, every node receives it and calculates the normalized distance as follows:

$$M_{ji}=\frac{Dji}{Trans_i}(6.17)$$

WhereD_{ji} is the distance between the sender node i and the receiving node j, $Trans_j$is the transmission range of the receiver node j. The weight function parameter allows nodes to select the best path and is defined by:

$$f_{ij} = \alpha * \frac{D_{ij}}{Trans_i} + \beta * \frac{V_{r_{ij}}}{V_{max_{ij}}}(6.18)$$

Where

α and β are the weightswhich satisfied $\alpha + \beta = 1$

Dij is the distance between node i and node j

$Transi$is the transmission range of the node i

$Vrij$is the relative velocity between node i and node j

$Vrmaxij$ is the maximum relative velocity between nodes i and j.

Calculate Mobility (M)
Estimate Distance between nodes (nD)
Calculate Residual Energy (RE) of each node
Find the distance between Source and Destination (Dist)
Add node Distance (nDist) as a possible route
Entry Expiration Time (ET) of a packet

Lastly joined Node (tNode)
If(nDist ≤ Dist) {
    Decrement hop-count by distance
    Select the route according to the node's current M and RE's values
}
Else {
Select the route according to the node's current M and RE's values
}
If (tNode did not receive any RREP) {
    Starts the rerouting process
}

Figure 6.9 Energy with Mobility and Distance-Aware Routing Algorithm (E-MDARA)

6.3.12Scheduling in MANETS

A fairness model for a MANET is efficient in determining the order in which packets are transmitted in the network. The rate of data transmission, the queue management, and the packet scheduling technique are all considered, the fairness in the transport layer flow is analyzed.

A suitable scheduling algorithm is used for processing the queued packet; the design aspect of the scheduling algorithm plays an important role in determining an end-to-end bandwidth of the flow of the respective packetwhich is equally shared among all the competing flows.

It not only provides the per-node fairness in rate but also achieves per-flow fairness in rate based on the transport protocol. For example, Sasikala and Wahidabanu (2014) stated thatconsidering thescheduling based on the per-flow conceptfor each flow, the delay parameter is maintained and given as follows:

$$Delay(dy)=WT+HT \quad (6.19)$$

Where Delay*(dy)* is the delay parameter maintained for each flow, *WT,* the Waiting Time of the packet in the queue prior to processing, and *HT,* the time required to send a packet to the next hop. The delay can be also calculated as an exponential average:

$$Delay(dy)=(w)dy+(l-w)Dy \quad (6.20)$$

Where$w$ is the current delay value calculated and is dependent on the previous one. A probe packet is sent by the source node in order to calculate the delay value in the intermediate nodes when a new flow has just started.However, referring to the exponential average delay calculation, no delay value is associated with the new flow at the startup and will be then estimated as follows:

$$Delay(dy) = \frac{1}{n}\sum_{\mathrm{n}}^{\mathrm{n}} \mathrm{dy_i} (6.21)$$

dy_i is i^{th} flow and its delay, and n is the number of active flows in the queue.

A queuing theory is sometimes needed to compensate for the weakness of a simple priority algorithm as it is not always effective. For example, the following are assumed: the arrival rate of packets obeys Poisson distribution, the service time obeys the general distribution scheme, and the buffer size is infinite. These can beanalyzedwith the following notations:

$\lambda_R$is the arrival rate of the routing packet, $\lambda_{D,}$the arrival rate of a data packet, $\lambda= \lambda_R +\lambda_D$is the overall arrival rate, and $\rho R = \frac{\lambda R}{\mu R}$is then therouting traffic intensity, where $\mu_{R,}$ is service rate for the routing packet. $\rho D = \frac{\lambda D}{\mu D}$ $\rho_D$is the data traffic intensity,$\mu_{D,}$ the service rate for the data packet, and $\rho=\rho R+\rho D$, the traffic intensity. $\bar{S}$is the available mean service time; a period of time with which the next packet has to wait while the current one is still being served and

$$W_R = \frac{\rho\bar{S}}{1-\rho_R} (6.22)$$

$$W_D = \frac{\rho\bar{S}}{(1-\rho_R)(1-\rho_R-\rho_D)} (6.23)$$

$W_R$and$W_D$are the mean resident times for both routing packets and data packets; the mean resident time of data packets is mainly dependent on the routing traffic intensity. Various problems arise especially, the queue buffer overflow events due to routing messages tending to occur in the burst, hence, always assigning the scheduling mechanism to routing packets is not advised. To overcome all those negative issues, different queue scheduling policies are adopted according to the current load of nodes (Chen et al. (2006)).

For example, with a Load-based Queue Scheduling technique, the length of the queue is a load indicator with three levels defined by two threshold values *Minth* and *Maxth*. The light load is the first levelwhose queue length is lesser than *Minth*. The second level is the medium loadwhose queue length is between *Minth* and *Maxth* while the heavy load is the onewhose queue length is bigger than *Maxth*.

As the scheduling policy, during the light load, all high priorities are assigned to all routing messages during the scheduling operations whereas, during the medium load, the forwarding delay and load achieve a balance, and the node nearly works in its stable state and packets are scheduled in a FIFO order. When the node is in a heavy load state, its buffer will quickly fill as it only has a few buffers left, in order to recover from this severe state in time, all newly arriving RREQ messages are dropped.

Optimal Threshold

When $Min_{th}$is too small or $Max_{th}$is too large, the route discovery process will be immediately affected by this event, setting the optimal threshold is necessary to this end. If the arrival rate of packets is known, the probability of the waiting queue whose length is bigger than k can be computed.

$$p=P(X_t>k)=1-\sum_{i=1}^{k} p_i \quad (6.24)$$

Wherep_i is the probability of the queue length i.

Concluded by,

$$p_i=P^i(1-\rho) \quad (6.25)$$

From p and p_i, $P=\rho^{k+1}$, the probability changes for the waiting queue in different input intensities.

Node and Route Urgency

In the proposed packet scheduling algorithm, the transmission priority of each packet is set based on each packet transmission urgency in order to deliver its sensitive data without any delay. In order to deliver delay-sensitive data over a multi-hop network, a packet scheduling mechanism is needed. To achieve this, three types of urgencies have been defined namely packet urgency, node urgency, and route urgency (Joo et al. (2011)).

A packet with a smaller residual delay to satisfy the end-to-delay requirement over the remaining hopsshould be transmitted more urgently to the destination in time. The node urgency is the sum of packet urgency of all the packets available in the buffer; larger node urgency indicates thepresence ofa lot of urgent packets in the buffer. To minimize the number of urgent packets, the packets with high transmission priority are transmitted and then loaded.

Thanks to this algorithm, data packet transmission priority is calculated according to the variation of the node urgency. The Route urgency is the sum of node urgencies of all the nodes along the route *R*.The route with minimum route urgency is selected as the target route for data transmission.

$$u_N(t) = \sum_{i=1}^{n_{pkt}} u_{pkt(i)}(t) (6.26)$$
$$u_R(t) = \sum_{j \epsilon R}^{n_{pkt}} u_{N(j)}(t) (6.27)$$

Where n_{pkt} is the number of packets in the buffer. $u_{pkt(i)}(t)$ is the packet urgency of the i^{th}packet in the buffer. $u_{N(j)}(t)$ is the node urgency of the j^{th}node along the route, and *R*denotes the route including all the intermediate nodes.

6.3.13 Routing

During the routing process, the clustering algorithm calculates the residual energy of each and every node by using the residual energy that was used in the cluster head election process. The cluster head updates its table with the new information obtained. This information concerns the hops between nodes, the available paths, the distance between them, the energy, etc.

S → Source Node
D → Destination Node
Dest_ID → Destination ID
Nch → Cluster-Head
Nch (n) → A set of Cluster-Heads in the network
MN → Malicious Node
NG → Gateway Node
NCH sends a Bait RREQ to the cluster members
If (RREP)
{

```
        Detect Malicious Node
}
S advertises the RREQ
The RREP is received by all nodes
n→ No. of Clusters in the network and i=1, 2, …, n
i=1
While (i<n)
{
        If (Nch(i).NTAB.Node_ID==Dest_ID)
        {
                Scheduling and transmitting the packets
                Break
}
        Else
        {
                Nch (i) sends the RREQ to the NGW
                Neighbor Nch(i+1) receives the RREQ
        }
i=i+1
}
```

Figure 6.10 Routing process with FSR-CAES

6.4 RESULTS AND DISCUSSION

6.4.1 Simulation Environment

Theexperiments are conducted with the Network Simulation version 2 (NS-2) to reveal the outperformance of the proposed scheme. The performance evaluation is conducted by comparing the proposed algorithms; FSR-CAES with the existing approach i.e. NCPR (Neighbor Coverage-based Probabilistic Rebroadcast) applying the parameters presented in Table 6.8. Codes are written in oTcl and C++, the collected data is printed on a trace file and processed using AWK tool. The results are then analysed, evaluated, and finally presented on graphs using the network animator (NAM).

The maximum number of nodes is set to 50 mobile nodes, each one with the transmission range of 250m. The nodes randomly move from one place to another within the simulation areawhose topology size is set to 1000m * 1000m. The Constant Bit Rate (CBR) for the relevant traffic managementis used in MANETs during the packet transmission process as well as for

TCP traffics, and the nominal bit-rate is set to 2 Mb/s. Each packet size is regularly ranging from 64 to 512 bytes and the network interface queue size for routing data packets set to 50 packets for all the four scenarios.

IEEE 802.11 for wireless LANs isused at the MAC layer with radio propagation model of Two-Ray Ground. A random waypoint model is used to model nodes movements which move with a speed uniformly distributed in the range between 1 and 20m/s. Both omnidirectional antenna and error-free wireless channel modelsare used. Each node canbe assigned a pause time, the period during which the node is still transmitting but stopsits motion for a while. If the pause time is 0 seconds thenode isin a continuous motion. In the simulation scenarios, broadcasting the routing packets to neighbor nodes and routes isalso performed.

6.4.2 Simulation parameters

Table 6.8 Simulation parameters and values

Simulation Parameters	**Values**
Simulator	Network Simulator 2
Topology Size	1000m*1000m
Number of Networks & their Size	50,100,150,200,250
Interface Type	Phy/WirelessPhy
Queue Length	50
Transmission Range	250m
Channel	Wireless Channel
MAC Type	IEEE 802.11
Queue Type	Queue/DropTail/PriQueue
Size of Packet	512
Nominal Bit Rate	2mbps
Antenna Type	Omni Antenna
Propagation Type	TwoRayGround
Nodes’ Mobility Speed	1…..20m/s
Traffic	CBR

The following four routing metricsare used to compare the performance of our proposed algorithm with the already existing ones.

These metrics are listed below:

- Routing Overhead
- Packet Delivery Ratio
- Normalized Routing Load
- Average End-To-End Delay.

Routing Overhead

The routing overhead refers to metadata and network routing information sent by an applicationwhich uses a portion of the available bandwidth of a communications protocol. Hence, it is the number of routing packets required for the network communication. The higher is the routing overhead in the network the more the MANET QoS is negatively affected. It affects the network performance to largerextentsand should be regularly minimized.

Packet Delivery Ratio

The packet delivery fraction is defined as the ratio of the number of data packets received at the destinations over the number of data packets sent by the sources. In other words, the fraction of successfully received packetswhich survive while finding their destination is called as packet delivery ratio.

Normalized Routing Load

Normalized Routing Load is defined as the fraction of all routing control packets sent by all nodes over the number of received data packets to the destination nodes. In other words, it is the ratio between the total numbers of routing packets sent over the network to the total number of data packets received.

Average End-To-End Delay

The average End-To-End Delay of a data packet is the total amount of the transmission delay of packets. It consists of propagation delays, queuing delay, retransmission delays, etc. The following table depicts the simulation parameters used in our experimentation.

6.4.3 Comparative Analysis

A performance evaluation was carried out by comparing theproposed scheme; FSR-CAES with the existing NCPR protocol.

NCPR (Neighbor Coverage-based Probabilistic Rebroadcast)

NCPR is one of the best routing protocols as it effectively reduces the routing overhead in Mobile Ad hoc Networks. It effectively exploits the neighbor coverage knowledge owing to a novel rebroadcast delay to determine the rebroadcast order and provides more accurate additional coverage ratio by sensing neighbor coverage knowledge. It also consists of a connectivity factor to provide the node density adaptation. By combining the additional coverage ratio and connectivity factor, a reasonable rebroadcast probability is obtained. This approach combines the advantages of the neighbor coverage knowledge and the probabilistic mechanismwhich can significantly decrease the number of retransmissions so as to reduce the routing overhead and can also improve the routing performance. This protocol has good performance when the network is in high density or the traffic is under heavy load.

NCPR protocol needs hello packets to obtain the neighbor information and carry the neighbor list in RREQ packet. In order to reduce the overhead of Hello packets, periodical Hello mechanisms are not used since a node sending any broadcasting packets can inform its neighbors of its existence, the broadcasting packets such asRREQ and route error (RERR) can play a role of hello packets. In order to reduce the overhead of neighbor list in the RREQ packet, each node needs to monitor the variation of its neighbor table and maintain a cache of the neighbor list in the received RREQ packet.

NCPR is an excellent QoS-routing protocol in MANETs as:

- It generates less rebroadcast traffic than the flooding and some other optimized schemes in the literature.

- It mitigates the network collision and contention, so as to increase the packet delivery ratio and decrease the average end-to-end delay.
- It has good performance when the network is in high-density or the traffic is under heavy load (Yadao and Krishna (2016)).

6.4.4 Simulation Results

A. Routing Overhead

As shown in Table 6.9 and Figure 6.11where the performance of the proposed scheme, FSR-CAES is compared with NCPR's, the performances of both the protocols are the same when the network size is set to 50 nodes, and start to differ slightly when the number of nodes begins increasing. For small, medium, and large-scale MANETs, the normalized routing overhead incurred by FSR-CAES is lower and never attains the NCPR's, thus making the proposed scheme a better one. The trend is due to manipulation of the neighbor coverage and performing the load balancing operations, the prominent features included in the proposed scheme. An interesting observation for both the protocols is that their normalized routing overheads progressively increasealmost in the same fashion asthe number of nodes isaugmented. The main reason for such an unfavorable event isthe proportional augmentation of the routing overhead with the increasing number of mobile nodes.

Table 6.9 Number of Nodes vs. Routing Overhead

Number of Nodes	Normalized Routing Overhead	
	FSR-CAES	NCPR
50	0	0
100	0.08	0.15
150	0.1	0.18
200	0.15	0.2
250	0.2	0.3
300	0.3	0.4

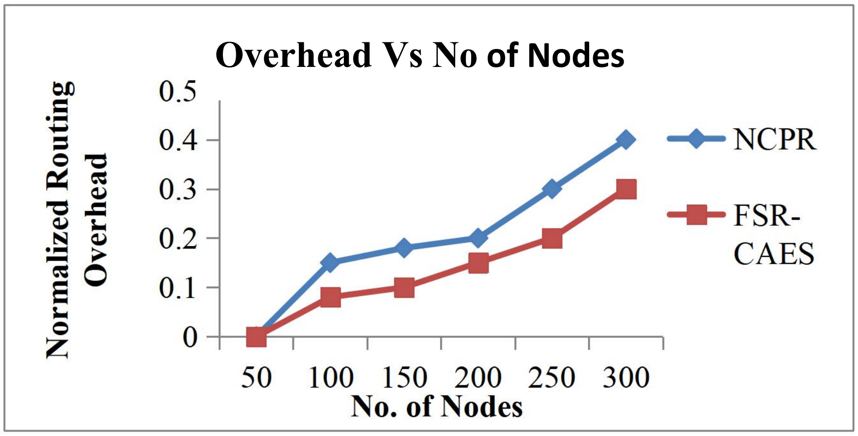


Figure 6.11 Number of nodes vs. Routing Overhead

B. Normalized Routing Load

Table 6.10 Number of Nodes vs. Normalized Routing Load

Number of Nodes	Normalized Routing Load [(%)]	
	FSR-CAES	NCPR
50	13	14
100	12	12
150	13	15
200	18	20
250	22	25
300	29	30

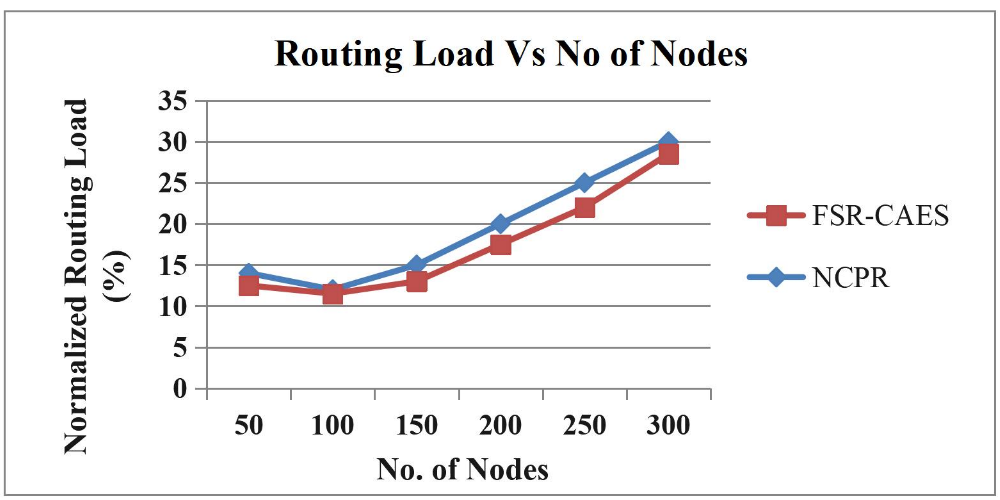


Figure 6.12 Number of Nodes vs. Normalized Routing Load

As it is evident in Table 6.10 and Figure 6.12, as long as the Normalized Routing Load parameter metric is concerned, both the protocols almost maintain a steady lower normalized routing load when the number of nodes ranges between 50 and 100. The normalized routing load starts progressively increasing when the number of nodes is above 100 and never decreases for the remaining simulation time.

The cause of the misbehavior isthe act of preventing high-speedy and malicious nodes from participating in the route discovery process which leads to finding a more stable route and reduce the routing overhead. However, it may lead to the network congestion and concentrate the routing load on certain nodes while others remain idle as the network grows. The proposed scheme, FSR-CAES, again outperforms as its Normalized Routing Load is maintained at the low level but with a minor difference with the NCPR's for medium and high-dense MANETs. As the number of nodes is about 300, the routing load of the proposed scheme is almost equal to NCPR's as seen in Figure 6.12

c. Packet Delivery Ratio

Table 6.11 Number of Nodes vs. PDR

Number of Nodes	Packet Delivery Ratio [(%)]	
	FSR-CAES	NCPR
50	98.3	98
100	98	97.5
150	97.8	97
200	97.6	97.25
250	97	96.5
300	96.8	96

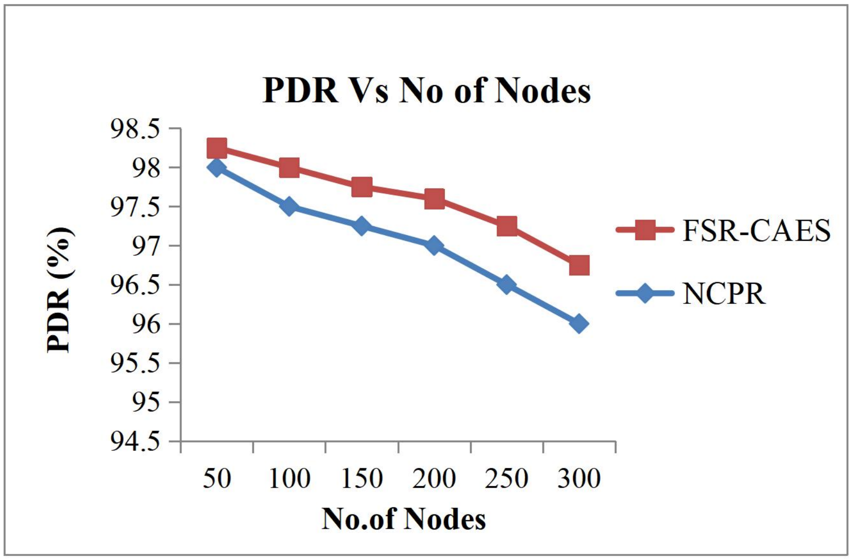


Figure 6.13 Number of Nodes vs. PDR

Table 6.11 and Figure 6.13 depict the performance of the proposed algorithm being compared to that of the NCPR using the Packet Delivery Ratio parameter against the Number of Nodes. At the starting time, when the number of nodes is set to 50, their PDRs are almost the same and high. Again, the performance of the proposed algorithm is the best as its PDR is higher for the overall simulation time even if it almost and progressively decreases as the network size increases which is contrary to those observed in Figure 6.11 and Figure 6.12, where, as the network sizeincreased, both the routing overhead and normalized routing load augmented in the same fashion, whatever can be the cause, this event generally leads to the drop in Packet Delivery Ratio.

D. Average End-to-End Delay

While again comparing the two protocols by varying the number of nodes and using the End-to-End delay as the evaluating parameter, the performances of bothprotocols are almost the same for small, medium, and larger network sizes (Table 6.12 and Figure 6.14). Even though the proposed scheme, FSR-CAESis exhibiting an excellent behavior as it maintains its average end-to-end delay lower than the NCPR's, the two protocols' delay ratios almost continually augment proportionally to the increasing number of nodes. The main cause is when the number of nodes increases, the path breaks and failures due to various factors such asdead nodes and malicious nodes occur which then force the source node to find an alternative route and consequentlyresulting in delays in the data route discovery, packet transmission, and retransmission processes.

Table 6.12 Number of Nodes vs. Average End-to-End Delay

Number of Nodes	Average End-to-end Delay [(secs)]	
	FSR-CAES	NCPR
50	0.3	0.4
100	0.4	0.5
150	0.45	0.5
200	0.55	0.6
250	0.7	0.8
300	1	1.2

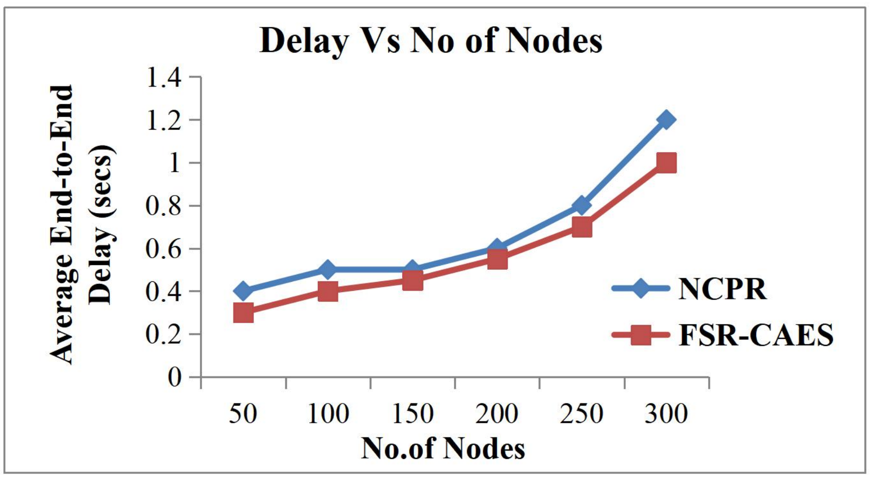


Figure 6.14 Number of nodes vs. Average end-to-end delay

6.5 SUMMARY

In this chapter, a robust clustering algorithm,Full-Featured Secure Routing Clustering Algorithm with Energy-Aware and Schedulingcapabilities(FSR-CAES) has been introduced for highly increasing QoS in MANET.FSR-CAESwas capable of first organizing the network into various clusters,each headed by the cluster headwhich identified the malicious nodes and then sent the information about the breach to another cluster head and prohibited them from participating in both route discovery and packets transmission processes. It also solved the problem concerning the energy constraints as some mobile nodes participating in the network operations are sometimes unexpectedly shutdown due to their lower battery power; this issue was solved by taking the power constraints of each nodeinto consideration, thus, increasing the whole network lifetime. The proposed scheme efficiently dealt with the scheduling problem by well determining the order inwhich the packets in the buffer were servedwhich further speeded up the packet transmission processes. The simulation results confirmed that theproposed scheme outperformed for all the cases studied as it highly enhanced the overall performance of MANETs by increasing the QoS during the routing processes as it incurred low routing overhead, low routing load, and highly increased packet delivery ratio with a minimized end-to-end delay. The outperformance was possiblethanks to various robust sub-algorithms comprising theproposed scheme, each one containing various problemswhich often affect the QoS provision in MANET.

CHAPTER 7

COMPARATIVE ANALYSIS OF THE PROPOSED QoS-AWARE ROUTING ALGORITHMS

Mobile Ad hoc Networks (MANETs) are of a great popularity as the wireless communication using mobile devices is of various advantages compared to wired networks, especially for real-time multimedia applications. Being infrastructureless, MANETs face various challenges inhibiting the routing protocols to achieve their expected goals. Due to this misbehavior, it is sometimes difficult to achieve high Quality of Service for these types of wireless networks, especially for multimedia data transmission such as video, animated video, audio, image, photo, etc. This often results in QoS degradationwhich further causes the reduction of the whole networkperformance.

To address this, various routing protocols aiming at providing efficient routing in MANETs have been proposed in the literature (Kaur (2015)).However, none of them is able to provide high QoS especially in transmitting data packets of different types. One of the negative issues prohibiting an increase in QoS provision in this type of Ad Hoc network is the network partitioning problem; this issue arises due to the fact that MANET topology is dynamic and composed of mobile nodeswhich frequently move out of the range while others unexpectedly joiningthe network and moving from a place to another randomly, thus, resulting in a hard-to-manage network with various shambles. Clustering is one of the approaches towards minimizing those problems as it helps in providing solutions to resource management-related problemsby achieving the process of partitioning the network into small groups, each one playing a major role as a disjointed cluster.

Some otherproblems related to the lifetime of nodes should not be neglected by the protocol designersas the whole network performance gradually degrades whenever some nodes are unexpectedly shutdown or restarted due to low battery power. The problem inherent to the security breaches incurring in the network is another negative issue frequently arising in MANETs as various intruders may act as normaland authentic nodes and steal or damage some packets passing through themor cause other network misuses. The fairness during packet transmission should also be taken into consideration using efficient packet scheduling algorithmswhichaccelerate the packet transmission rate and avoids problems associated with the packet routing processes such ascollision, delay, routing overhead, and interference. They also alleviate various problems relating to packet queuing operations.

Designing and implementing a multi-algorithm QoS-aware routing protocol capable of transmitting multimedia data and aiming at eliminating those previously mentioned negative issuesis challenging. In this research work, to provide high Quality of Service in MANET, various QoS mechanisms have been proposednamely QAMACF(QoS-Aware transmission for Multimedia applications using Ant Colony with Fuzzy optimization), a protocol implemented based on Ant Colony Optimization and Fuzzy Logic techniques, GDAQM(Genetic with DPD for Attaining high QoS in MANETs), a very effective and robust algorithmwhich is a combination of both Genetic and MDPD-k scheduling algorithms, MARMAQS(Multi-Algorithm Routing Mechanism for Acquiring high Quality of Service in MANET), a routing mechanism very effective in achieving high QoS in terms of highly increased transmission reliability, network lifetime, packet delivery ratio, throughput, and decreased both end-to-end delay ratio and routing overhead, and FSR-CAES(Full-Featured Secure Routing Clustering Algorithm with Energy-Aware and Scheduling capabilities for highly increasing QoS in MANET), an efficient clustering techniquewhich is a combination of numerous algorithmseach one containing one of the previously mentioned problems. All those QoS routing algorithms share almost the same goal; achieving high QoS especially in transmitting multimedia data over MANETs, each one having its own features, enhancements, and achievements.

This chapter aims to provide a comparative evaluation of those proposed protocols using various prominent QoS provision techniques i.e. power-aware algorithms, clustering mechanisms, multicasting features, packet scheduling techniques, multipath routing, and intrusion detection schemes, anddifferent evaluating parameter metrics namelypacket delivery ratio, end-to-end delay, throughput, routing overhead, energy, route reliability, normalized routing load, and packet loss ratio.

7.1 Comparison of QoS-Aware Routing Protocols for Multimedia Applications

Table 7.1provides the comparative outcomes of theproposed QoS-aware routing protocols implemented using prominent techniqueswhich have been popular dueto their regular contribution inincreasing the QoS of MANETs; QoS metrics, multicast features, multimedia applications, energy-aware routing, intrusion detection, clustering techniques, and packet scheduling.

Table 7.1 Comparison of the proposed QoS Protocol for Multimedia Applications

Routing Algorithms	QoS Metrics	Multicast Features	Multimedia Applications	Energy-Aware Routing	Intrusion Detection	Clustering Technique	Packet Scheduling
QAMACF	Yes	Yes	Yes	Yes	No	Yes	Yes
GDAQM	Yes	Yes	Yes	Yes	No	Yes	Yes
MARMAQS	Yes	No	Yes	Yes	Yes	No	Yes
FSR-CAES	Yes	No	Yes	Yes	Yes	Yes	Yes

7.2 Results and Discussion

7.2.1 Simulation environment

The comparative experiments are conducted using the NS-2 simulator. The simulation environment is created with the NS-2.35 version on Ubuntu 14.10 platform to study the performance of the proposed routing protocols. While oTcl is used as the frontend language, the C++ is used on the backend side.

The simulation study is divided into the following steps. These are:

Step 1: Create a TCL file for each protocol.

Step 2: Generate a Scenario file.

Step 3: Generate a Network Traffic file.

Step 4: Integrate the Scenario file and Network Traffic file with the TCL file.

Step 5: Execute the TCL file for the generation of a trace file.

Step 6: Use the AWK script to execute the trace file to get the performance metrics of each routing protocol.

The TCL file is created with the .tcl extension which describes the characteristics of each node, number of nodes used in topology, number of sources and destinations, traffic application and mobility model. Scenario file describes the exact motion of each node with the random waypoint mobility model. The network traffic file describes the type of traffic used in the application, the maximum number of connections to be setup between nodes and the rate at which the packets are transmitted.

Table 7.2 Simulation parameters and values

Simulation Parameters	**Values**
Simulator	Network Simulator 2
Topology size	1500m*1500m
Number of Networks & their Size	5, 10, 15, 20
Interface type	Phy/WirelessPhy
Queue length	40 Nodes
Transmission range	250m
Channel	Wireless Channel
MAC type	IEEE 802.11
Queue type	Queue/DropTail/PriQueue
Size of Packet	512
Nominal Bit Rate	2mbps
Antenna Type	Omni Antenna
Propagation Type	TwoRayGround
Nodes' mobility speed	1…..30m/s
Traffic	CBR

The maximum number of nodes is set to 20 mobile nodes, each one with the transmission range of 250m. The nodes randomly move from one place to another within the simulation areawhose topology size is set to 1500m * 1500m. The Constant Bit Rate (CBR) is used for the relevant traffic management in MANETs during the packet transmission process as well as for TCP traffics, and the nominal bit-rate is set to 2 Mb/s. Each packet size is 512 bytes, and the network interface queue size for routing data packets is set to 40 packets for all the four scenarios.IEEE 802.11 for wireless LANs is used at the MAC layer with radio propagation model of Two-Ray Ground. A random waypoint model is used to model movements of nodes which movewith a speed uniformly distributed in the range between 1 and 30m/s. Both omnidirectional antenna and error-free wireless channel models are used.

7.2.2 Routing Load

Table 7.3 Comparative results of the proposed schemes using routing load

Number of Nodes	Routing Load			
	FSR-CAES	GDAQM	MARMAQS	QAMACF
0	0	0	0	0
5	12.5	4.7	5	40
10	12	8.5	9	6
15	13	13	14	15
20	17.4	17.4	22	14

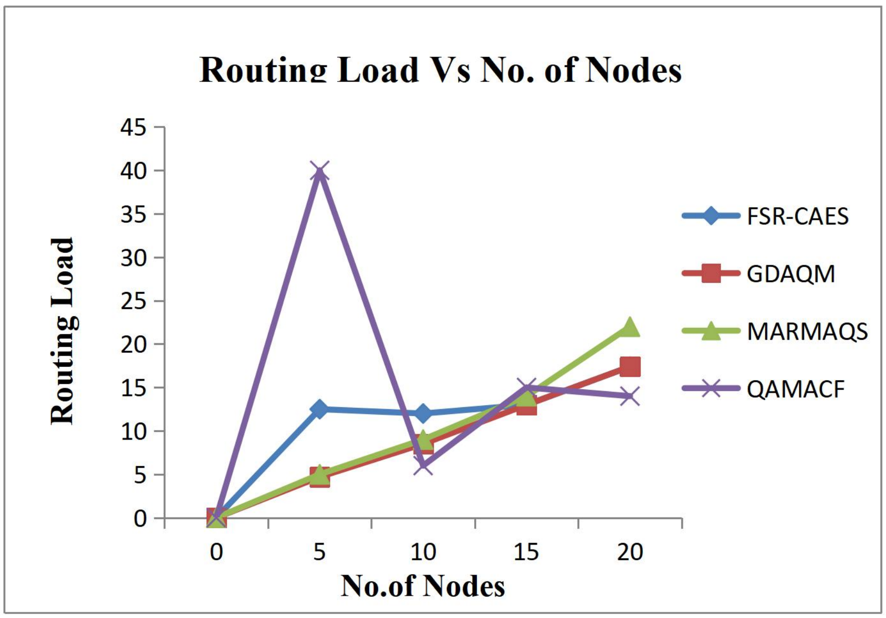


Figure 7.1 Comparative results of the proposed schemes using routing load

As observed in Figure 7.1, the four proposed protocols which have previously been proposed namely QAMACF, GDAQM, MARMAQS, and FSR-CAES are compared using the routing load as an evaluating parameter metric. All the protocols always perform well as their normalized routing load is not affected significantly when the number of nodes is increased. A slight augmentation of the routing load is evident almost in the same fashion as the network size grows. When the number of nodes is set to 20, QAMACF's routing load gradually increases and attains as high as 40 but immediately dropping to 6, when the number of nodes is 10.

7.2.3 Throughput

Table 7.4 Comparative results of the proposed schemes using throughput

Number of Nodes	Throughput [(Mbps)]			
	FSR-CAES	GDAQM	MARMAQS	QAMACF
0	0	0	0	0
5	47	46	47	49
10	90	49	60	70
15	92.5	55	65	60
20	95	70	86	73

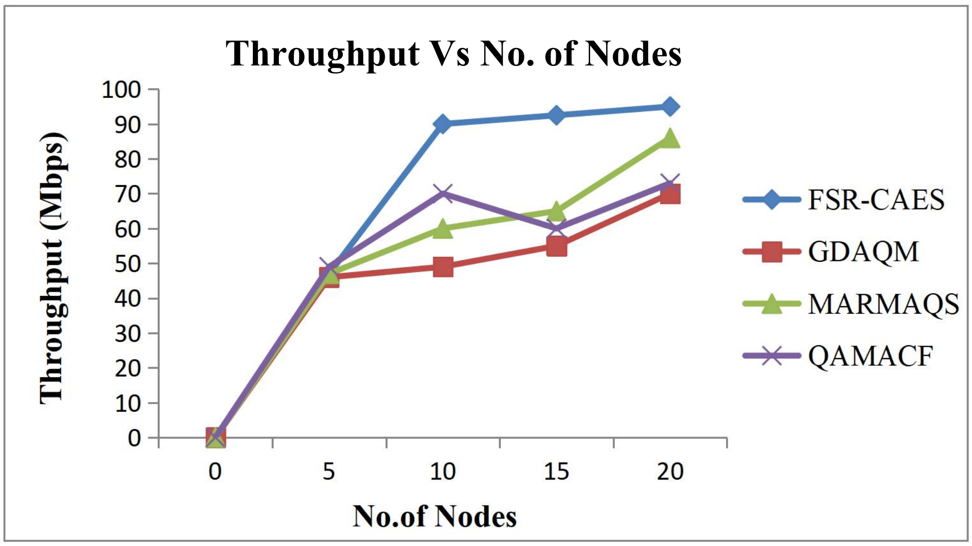


Figure 7.2 Comparative results of the proposed schemes using Throughput

In both Table 7.4 and Figure 7.2, the outcomes of the comparative evaluations of FSR-CAES, GDAQM, MARMAQS, and QAMACF are presented. FSR-CAES slightly outperforms other routing protocols as its throughput almost and progressively increases with the increase in the number of nodes; this is due to the fact that it partitioned the network into various clusters, each headed by a cluster head which controlled the whole cluster resulting in higher levels of availability, reliability, and stability, thereby maximizing the throughput of the network. An overall observation for all the protocols is that their throughputs gradually increases when the network size changes which means that the network size does not affect the throughput of the protocols very much.

7.2.4 Reliability

Table 7.5 Comparative results of the proposed schemes using reliability

Number of Nodes	Reliability			
	FSR-CAES	GDAQM	MARMAQS	QAMACF
0	0	0	0	0
5	22	92	90	92
10	49	118	128	130
15	98	142	165	147
20	104	161	208	181

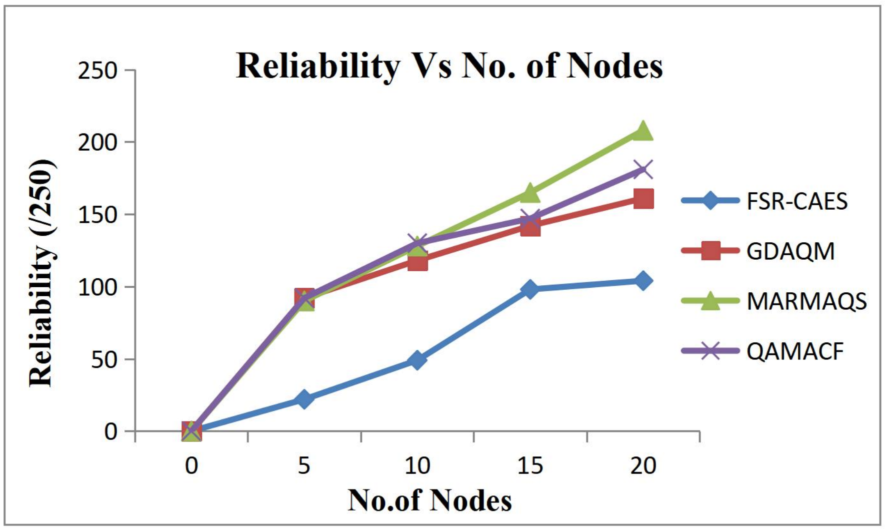


Figure 7.3 Comparative results of the proposed schemes using reliability

As seen in Figure 7.3, MARMAQS is exhibiting an excellent behavior as it maintains a higher reliability than FSR-CAES, GDAQM, and QAMACF. FSR-CAES does not perform very well as its routing reliability is maintained at lower levels for the overall simulation time. When the number of nodes ranges between 0 node and 5 nodes, the routing reliability ratios of GDAQM, MARMAQS, and QAMACF are almost the same and start to differ slightly as the number of nodes is increased. One interesting revelation about all the protocols is that they exhibit good behavior as their route reliability ratios continue increasing even when the number of nodes changes; this is due to the fact that those protocols select reliable routes during the packet transmission processes.

7.2.5 Packet Delivery Ratio (PDR)

The routing protocol in MANETs must ensure that the packet delivery ratio is maintained at a high level. In figure 7.4, one can observe an interesting case, where all the four protocols perform very well as their PDRs are almost identical for all network sizes. QAMACF's PDR remains slightly higher with a minor difference to other protocols' during the overall simulation time. The four protocols are successfully capable of transferring a large number of packets to the destination which means a small number of packets have been dropped during their transmission process. Another observation is the PDR almost and progressively increasing proportionally to the number of nodes.

Table 7.6 Comparative results of the proposed schemes using PDR

Number of Nodes	Packet Delivery Ratio [(%)]			
	FSR-CAES	GDAQM	MARMAQS	QAMACF
0	0	0	0	0
5	50	45.6	55	55
10	60	59	62	67
15	77	70	65	80
20	90	94	89	93.5

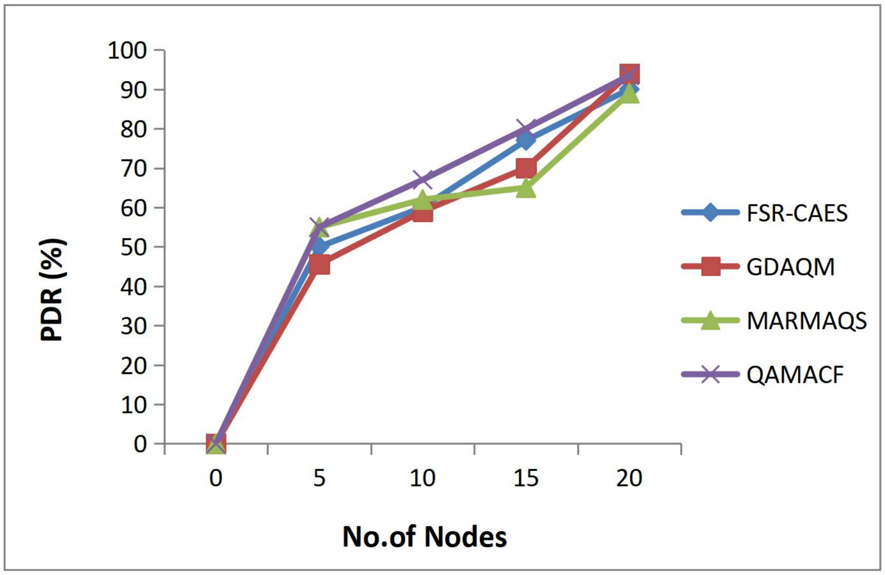


Figure 7.4 Comparative results of the proposed schemes using PDR

7.2.6 Packet Loss

In Table 7.6 and Figure 7.5, the comparative analysis of the proposed schemes is presented by exhibiting the packets lost during their transmission. This is another interesting case as all the four protocols minimize the packets lost during multimedia data transfer and their packet loss ratios neither increase nor decrease very much. FSR-CAES outperforms other protocols as its packet loss ratio is lower for the overall simulation time. When the number of nodes is 20, the packet loss of FSR-CAES begins to go down and to null.

Table7.7 Comparative results of the proposed schemes using packet loss

Number of Nodes	Packet Loss			
	FSR-CAES	GDAQM	MARMAQS	QAMACF
0	0	0	0	0
5	1	4	6.5	1
10	1	7	5	10
15	1	6	4	5
20	0	2	1	2

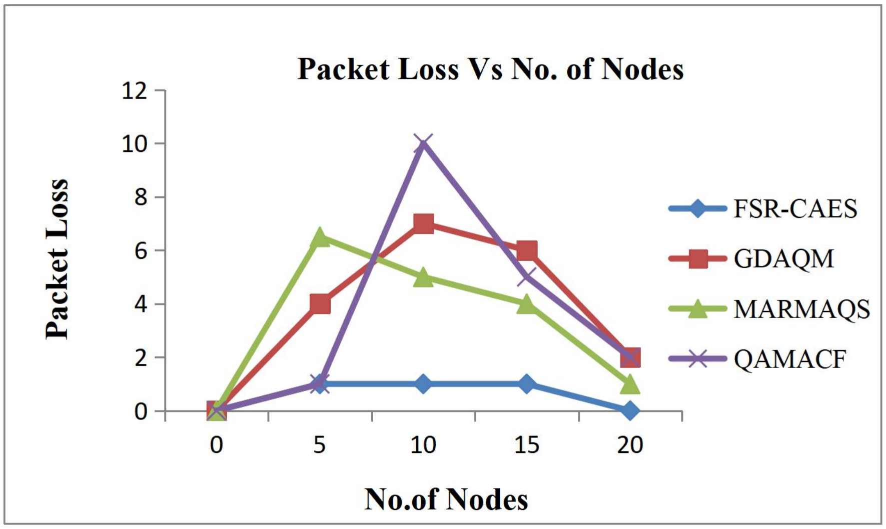


Figure 7.5 Comparative results of the proposed schemes using packet loss

7.2.7 Overhead

Table 7.8 and Figure 7.6 present the comparative results of the proposed protocols using the routing overhead as an evaluating parameter. FSR-CAES incurs low overhead compared to the other three protocols. The outperformance of FSR-CAES in minimizing the overhead is possible due to the clustering technique which lowered the amount of routing overhead incurred in the network. GDAQM, MARMAQS, and QAMACFperform well and almostin the same manner, their routing overheads shapes are in crisscross patterns.

Table7. 8 Comparative results of the proposed schemes using routing overhead

Number of Nodes	Overhead			
	FSR-CAES	GDAQM	MARMAQS	QAMACF
0	0	0	0	0
5	0	0.1	0.01	0.02
10	0.08	0.01	0.3	0
15	0.1	0.3	0.05	0.3
20	0.14	0.2	0.2	0.2

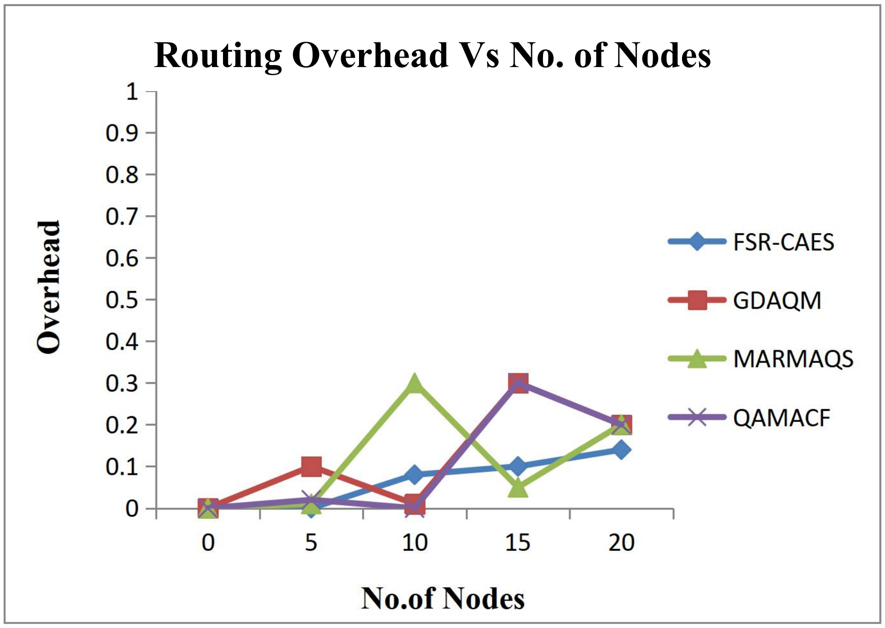


Figure 7.6 Comparative results of the proposed schemes using routing overhead

7.2.8 Energy

In MANET, all nodes such as source, destination, and intermediate nodes situated along a specific path should have high energy all the time for their uninterrupted services. If the energy is lower for any node in the network, for example, an intermediate node, the node will be shutdown sooner resulting in the path break which may cause path fails and packets will be immediately lost. This will affect the whole network and degrade its performance.

As seen in Table 7.9 and Figure 7.7, FSR-CAES and QAMACF well manage the energy consumption during multimedia data transmission processes. MARMAQS and GDAQM work mediumly as an average energy was consumed by the nodes. As an overall observation for all protocols when the number of nodes is increased, the energies consumed during packet transmission operations are slightly increased.

Table 7.9 Comparative Results ofProposed Schemes Using Energy

Number of Nodes	**Energy [(Joule)]**			
	FSR-CAES	**GDAQM**	**MARMAQS**	**QAMACF**
0	0	0	0	0
5	0.01	0.1	0.2	0.02
10	0.1	0.2	0.3	0.1
15	0.3	0.3	0.5	0.25
20	0.4	0.5	0.5	0.4

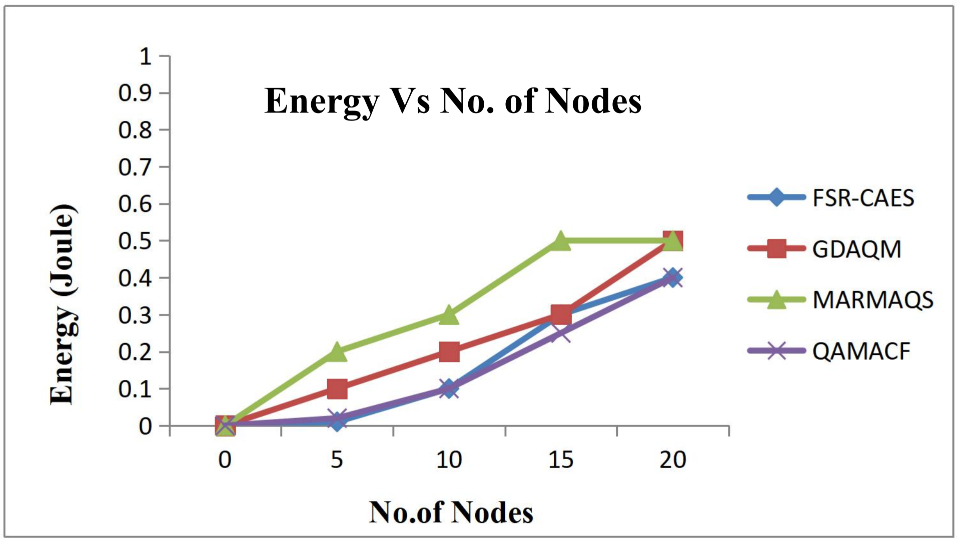


Figure 7.7 Comparative results of the proposed schemes using energy

7.2.9 Delay

Higher throughput and less value of delay will improve the performance of the network for the overall network lifetime but it is a challenging task in MANET. However, as implicated in Figure 7.10, the routing protocol, FSR-CAES is exhibiting an excellent behavior as it maintains a steady end-to-end delay ratio lower than the other protocols for the overall simulation. GDAQM, MARMAQS, and QAMACF are also performing well. For QAMACF, when the number of nodes is set to 10, its delay ratio attains50 and decreases for the remaining simulation time.

Table 7.10 Comparative results of the proposed schemes using Delay

Number of Nodes	Delay [(ms)]			
	FSR-CAES	GDAQM	MARMAQS	QAMACF
0	0	1	0	0
5	10	7	10	10
10	5	9	50	51
15	6	9	40	40
20	4	8	20	30

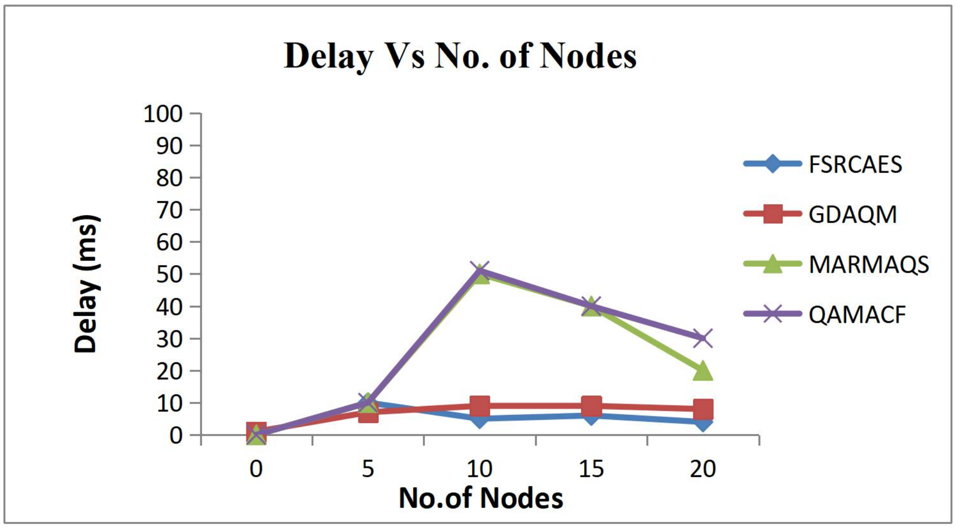


Figure 7.8 Comparative results of the proposed schemes using Delay

7.3 Summary

In this chapter, a comparative analysis of the proposed QoS-Aware routing protocols for efficient routing in Mobile Ad hoc Networks was conducted. Increasing the Quality of Service in MANETs is the most prominent featurewhich every protocol designer should take into consideration while implementing a robust routing protocol otherwise the QoS provision would be hard to achieve. Even if it is not easy, providing QoS guarantees has become an essential feature for the operation of multimedia applications. Acomparative study oftheproposed QoS-aware routing protocols for MANETsnamelyQAMACF, GDAQM, MARMAQS, and FSR-CAES is presented in this chapter. Those protocols share the same goal of providing high QoS in MANET but they have different featureswhich make a protocol better or not compared to another. Those routing protocols were compared in terms ofpacket delivery ratio, end-to-end delay, throughput, routing overhead, energy, route reliability, normalized routing load, and packet loss ratio.

The performance evaluation with throughput revealed that FSR-CAES outperformed other protocols as its throughput progressively increased for the overall simulation time. Concerning the route reliability parameter, GDAQM, MARMAQS, and QAMACF exhibited a better behavior rather than FCR-CAESwhose reliability never attained the others', while for both PDR and routing load, all the four protocols performed almost in thesame way astheir normalized routing load ratios were lower and their PDR ratios were high even when the number of nodes was set to 20. Regarding the packet loss, all the protocols performed well as the lost packets were minimized; the same did not always apply to QAMACF as when the network topology was made of 15 nodes, theratio of lost packets started increasing and never got down for the remaining simulation time. For the overhead, all the four protocols performed well as their overhead ratios were maintained at lower levels (less than 3). Regarding the energy parameter metric, it was revealed that the energy consumed augmented proportionally to the increasing number of nodes but all theproposed schemes managed well the power consumed by nodes as the energy level of all theprotocols did not attain a high level during the simulation time. Concerning the end-to-end delay, FSR-CAES outperformed other protocols as it maintained the end-to-end delay ratio lower while other protocols performed mediumly.

As an overall observation, the proposed schemes performed well as each simulation results revealed that no protocol was performing worse even if some were performing normally in some cases and outperformed better in others.Hence, it is confirmed thatthe proposed schemes are well suited for high QoS provision for multimedia applications in MANET.

CHAPTER 8

CONCLUSION AND FUTURE WORKS

8.1 CONCLUSION

MANET is one of the leading wireless networkswhich have been playing an important role in day-to-day life due to various advantages it provides. Being an infrastructureless wireless network and able to be deployed anywhere at any time for any purpose, this kind of wireless network does not require any costly equipment for its installation. Routing and transmitting various information from one end to another is the main objective of deploying any type of network.In MANET, it is sometimes difficult to achieve this objective due to various challenges caused by its inherent properties such as dynamic topology, wireless shared link, the mobility of nodes, etc.

One of those negative issues affecting the whole network performance is the failure in providing high QoS, the most prominent feature which every protocol designer should take into consideration while implementing a robust routing protocol otherwise the QoS provision would be impossible to achieve. Providing a high QoS is one of the most investigated techniques in wireless networks,especially for transmitting ordinary data packets in MANETs. The problem is how to design an efficient QoS schemewhich takes into account the probability of successful reception of either multimedia or ordinary data. Designing a routing protocol in wireless networkswhich consists of providing a high QoS is a difficult task as it has to becomprised of various sub-algorithms, each one achieving different routing objectives.

Providing high Quality of Service for transmitting an ordinary data packet does not necessitate rigorous requirements.However, this becomes a big issue while relaying multimedia data in real-time applicationsas this kind of information, for example, a video streamrequires some additional features in the Quality of Service provision. Providing high QoS requires design and implementation of more than one rigorous QoS algorithm in order to provide various solutions to different problems relatedto this matter. One of the main negative issues is related to the multicast stormwhich is caused by an extreme amount of broadcast trafficsconsumingsufficient huge amount of network resources so as to render the network unable to transport either ordinary or multimedia data packets. Another problem is related to the energy constraintswhere some nodes are dead due to their low battery powerwhich results in degradation of the whole network performance. The third negative issue relates to the fairness issue often neglected while transmitting the packets; a packet scheduling algorithm is required to minimize the routing delay, provide fairness between packets, and much more. A very dangerous negative issue is the security breaches incurred in the network by malicious nodes and intruders regularly acting as normal nodeswhich cause the network misuse and security attack. The last and serious problem relates to the network management issues, the unpartitioned network is hard to manage, and an efficient QoS protocol specialized in the clustering technique is required to divide the network into small manageable clusters.

Various routing protocols have been designed aiming at providing high QoS for transmitting ordinary data but leaving behind the real-time multimedia applicationsas only a few ones exist in the literature. To date, none of them highly solves the problems inhibiting high QoS achievements either for ordinary or multimedia data transmission. In thisstudy, a different approach was usedasnew and robust QoS-aware routing algorithms were proposed using different QoS provision techniques, each one taking into account all those negative issues previously mentioned.

The first mechanismwhich is described in Chapter 3; QAMACF(QoS-Aware transmission for Multimedia applications using Ant Colony with Fuzzy optimization) is a prominent QoS protocolwhich considers two important techniques in providing high QoSnamelyACO (Ant Colony Optimization) and Fuzzy Logic mechanisms. For the performance evaluation purposes, the parameter metrics such asDistance (Dt), Residual energy (Re), and Reachability (Rc) were used. Those parameters were collected using ACO technique at each node by a F_ANT and forwarded tothe fuzzy logic system, which in turn generated a combination of 27 different fuzzy rules according to the input parameters provided from the fuzzy rule base available from the Fuzzy Inference System (FIS). FISthen calculated the probabilistic valueswhich were used to decide whether a path could be selected as the best route. The optimal path found was then used to relay multimedia data packets from source to destination, the route maintenance operations were required whenever a route failed or broke, an alternative path was used instead. Varying the number of nodes and receivers, the performance evaluations were carried out using the NS-2 simulator by comparing the proposed scheme with the ones existing in the literature namelyACO, ABC, Fuzzy integration with ACO, and Dynamic

Core Based Multicast Routing Protocols (DCMP). Prominent QoS parameters such as the end-to-end delay, PDR, and throughput were also used during theexperimental analysis. The simulation outcomes revealed that for all the scenarios, the proposed scheme, QAMACF outperformed the existing algorithms. The achievement was possiblethanks to its multiple features combined together enabling the protocol to provide solutions to various problems relating to QoS provision in MANET and successfully increasing the QoS during thetransmission process of either ordinary or multimedia data.

In Chapter 4, GDAQM (Genetic with DPD for Attaining high QoS in MANETs), another enhanced new technique different fromthe other proposed schemes in this thesis, has been introduced.It includes bothGenetic Algorithm (GA) and MDPD-k (Modified DPD-k) scheduling algorithm. The former technique achieved a very high QoS as it selected the least-cost, maximum-bandwidth, and energy-efficient path and aimed at finding out the best route between a source and multiple destinations (multicast).MDPD-k scheme efficiently performed the packet scheduling operations. Combined together, those two techniques resulted in a very effective algorithm able to achieve successful multimedia data transmission. Those techniques were implementedusing: tree-structure based encoding method, mutation, and efficient crossover techniques instead of coding/decoding operationswhich enabled theGenetic Algorithm to successfully achieve the route identification process. Upon completing those route discovery operations, the packet schedulerwhich maintained packets in the queuewas then used to identify the packet urgency by calculating two threshold valueswhich were compared to each packet slack time. A decision was then made whether a given packet had to be urgently served or not using three different conditionswhich resulted in successfully providing fairness among various and the competing flows. A set of experiments was conducted on GDAQM routing protocol using the NS-2 simulator in comparison with the QoS routing protocolsexisting in the literaturenamely AODV with GA, GA, Energy-GA, and EDGA by varying both the number of nodes and their respective speeds. The proposed algorithm outperformed in terms of PDR (Packet Delivery Ratio), throughput, delay, and energy for the overall simulation time.

Chapter 5 provides another proposed QoS algorithm, MARMAQS (Multi-Algorithm Routing Mechanism for Acquiring high Quality of Service in MANET) which is a compound protocol consisting of prominent QoS provision techniquesnamely intrusion monitoring mechanism, packet scheduling algorithm, and node and link lifetime prediction scheme. The intrusion detection technique provided a security mechanism by detecting intruders and malicious nodes and preventing them from participating in the multimedia data packet routing processes. The second mechanism isthe packet scheduling technique:Urgency based Packet Scheduling (UPS) algorithm, which, using an urgency calculation mechanism arranged packets in the buffer in an ordered manner and then scheduled them during the transmission using the priority of both nodes and packets. The latter one, Lifetime Prediction Routing (LPR) scheme consisted of route discovery, route selection, transmission process, and route maintenance operations. In comparison with the existing mechanisms namely PNLP, IRS, LPR, MARMAQSwas evaluated using parameter metrics namelypacket delivery ratio, end-to-end delay, reliability, routing overhead, and throughput by varying both the number of nodes and moving speed of nodes. The outcomes revealed that the proposed algorithm MARMAQS exhibited better behaviors for all the studied cases as it increased the rate of PDR, route reliability, and throughput while minimizing very much the routing overhead and end-to-end delay ratios.

In chapter 6,a robust clustering algorithm; Full-Featured Secure Routing Clustering Algorithm with Energy-Aware and Scheduling capabilities(FSR-CAES)has been proposed for highly increasing QoS in MANET.The proposed scheme is a robust QoS protocol as it was able to organize the whole network into a number of clusters and selecting a special node, the cluster headwhich controlled all the operations in the whole cluster. Prominent features of the cluster head nodeincluded its ability to play dual roles as inter- and intra-cluster coordinator. It was also abletoidentify various security breaches incurred in the network by malicious nodes and prevent such nodes from participating in both route discovery and packet transmission processes.FSR-CAES provided another prominent feature, the energy management mechanism. As nodes sometimes were shutdown or restarted due to their lower battery power, the proposed scheme was able to deal with the power constraints at each nodewhich resulted in the better performance of the whole network in terms of its overall lifetime. Another advantage provided by the proposed scheme wasthe scheduling mechanismwhich determined the order in which all the packets residing in the buffer would be served, thus, achieving the fairness operation, avoiding congestion and routing overhead events which further resulted in speeding up the route transmission process. The experimental evaluations were carried out in the NS-2 simulatorwherein the performance of the proposed scheme was compared with the existing QoS protocol,NCPR (Neighbor Coverage-based Probabilistic Rebroadcast); a routing protocol specialized in providing high QoS in MANETs as it is effective in reducing the routing overhead in the network. The results presented revealedthat theproposed scheme outperformed NCPR as it highly increased the Quality of Service by increasing the PDR and at the same time minimizing the routing overhead, routing load, and end-to-end delay.

Compared to traditional QoS routing protocols, the proposed schemes outperformed for all the cases studied as they efficiently increased the Quality of Service during multimedia data transmission in MANETs. The last contribution of the present work appears in Chapter 7 of this thesiswhich brings about the outcomes of performance evaluation of the proposed schemes byvarying the number of nodes and evaluating parameter metricsfor all the studied cases.All the proposed schemes exhibited a good behavior as it was revealed that each protocol performed well for some experimentations and outperformed for others.Hence, it is ensured that the proposed schemes are efficient in increasing the Quality of Service for multimedia applications.

8.2. FUTURE WORKS

Despite the significant advances in the broader area of wireless ad hoc networks, the issues addressed in this thesis are still under active research. In this research work, we have addressed a number of challenging but important issues for supporting adaptive QoS in wireless ad hoc networks. While much additional work remains to be done, this thesis offers important contributions to the vision of realizing tomorrow's system.

On the right of thefindings of the current research work, we recommend the following:

- First, only afew robust standard QoS-aware routing protocols for real-time multimedia applications exist in the literature, a deeper research should be done in this field about the transmission of any kind of data.
- Second, theproposed schemes can be extended by deeply taking into account multi-path routing so as to avoid interference during transmission.
- Third, future researchers should extend the current work reported in this thesis by dealing with the improvement of the network lifetime and stability in MANETs with speedy nodes. This can be done by predicting the future node and link lifetime as well as the future direction of the mobile nodes.

- Fourth, the comparative study of theproposed schemes can be extended by conducting a more advanced comparison of the same protocols within a larger network size by varying the number of nodes and node speedsincetheexperiments were conducted only on small networks of maximum 20 nodes moving at the same speed, in the present study.
- Finally, the experimental evaluation of the proposed model in a real testbed, including indoor, outdoor, and mobile nodes would give more insights intoitsprediction capacity in a larger set of experiments.

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