A NOVEL DYNAMIC SOURCE ROUTING (DSR) PROTOCOL BASED ON MINIMUM EXECUTION TIME SCHEDULING AND MOTH FLAME OPTIMIZATION (MET-MFO)

SALEM A. ALMAZOK

A Novel Dynamic Source Routing (DSR) Protocol based on Minimum Execution Time Scheduling and Moth Flame Optimization (MET-MFO)

NEU 2020

A THESIS SUBMITTED TO THE GRADUATE SCHOOL OF APPLIED SCIENCES OF NEAR EAST UNIVERSITY

By
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In Partial Fulfillment of the Requirements for the Degree of Doctor of Philosophy

in

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Approval of Director of Graduate School of Applied Sciences

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ACKNOWLEDGMENTS

Firstly, I would like to express my sincere gratitude to my advisor Prof. Dr. Bülent Bilgehan for the continuous support of my Ph.D. study and related research, for his patience, motivation, and immense knowledge. His guidance helped me in all the time of research and writing of this thesis. I could not have imagined having a better advisor and mentor for my Ph.D. study.

Besides my supervisor, I would like to thank the Ph.D. advisor Assist. Prof. Dr. Ali SERENER for his insightful comments and encouragement, his patience in all the time of the Ph.D. program.

Lastly, I will also like to appreciate my family for their support and backup as well as every other person that has contributed to the success of this study.

To my parents…

ABSTRACT

In general, the conventional routing approaches in Mobile Ad hoc Networks (MANETs) provide a route between the source and the target with a minimum hop count. Dynamic source routing (DSR) as a typical prototype of routing protocols that relies on the minimum hop count parameter to provide the path without considering any other factors such as energy consumption and node energy level, which significantly affect the routing algorithm performance. To enhance the performance of the DSR, a novel and efficient routing mechanism based on a hybrid approach using the Minimum Execution Time (MET) scheduling and Moth Flame Optimization (MFO) scheme is proposed. This hybridization version of DSR is called the (MET-MFODSR) algorithm and it aims to improve the routing mechanism through establishing an optimal route with minimum energy consumption, which increases the network lifetime and reduces route failure issues. The proposed MET-MFODSR protocol is implemented using the MATLAB platform, analyzed and evaluated in different simulation environments. The simulation results demonstrate that the suggested routing algorithm is applicative, practicable and its performance exceeds the performance of the existing Bee DSR (BEEDSR) and bee-inspired protocol (BeeIP) algorithms.

Keywords: Optimal route; Minimum Execution Time (MET) scheduling; Moth Flame Optimization (MFO); Ad hoc Network; Dynamic Source Routing (DSR) approach.

ÖZET

Genel olarak, Mobil Ad hoc Ağlardaki (MANET'ler) geleneksel yönlendirme yaklaşımları, kaynak ve hedef arasında minimum atlama sayısıyla bir yol sağlar. Yönlendirme algoritma performansını önemli ölçüde etkileyen enerji tüketimi ve düğüm enerji seviyesi gibi diğer faktörleri dikkate almadan yolu sağlamak için minimum atlama sayısı parametresine dayanan tipik bir yönlendirme protokol prototipi olarak dinamik kaynak yönlendirme (DSR) kullanılmaktadır. DSR'nin performansını artırmak için, Minimum Yürütme Süresi (MET) çizelgeleme ve Güve Alev Optimizasyonu (MFO) şemasını kullanan karma bir yaklaşıma dayalı yeni ve verimli bir yönlendirme mekanizması önerilmektedir. DSR'nin bu hibridizasyon versiyonuna (MET-MFODSR) algoritması denir ve minimum enerji tüketimiyle optimum bir rota oluşturarak yönlendirme mekanizmasını iyileştirmeyi amaçlar. bu da ağ ömrünü uzatır ve rota hatası sorunlarını azaltır. Önerilen MET-MFODSR protokolü MATLAB yazılımı kullanılmıştır. Simülasyon sonuçları, önerilen yönlendirme algoritmasının uygulanabilir, uygulanabilir olduğunu ve performansının mevcut Bee DSR (BEEDSR) ve arıdan ilham alan protokol (BeeIP) algoritmalarının performansını aştığını göstermektedir.

***Anahtar Kelimeler*:** Optimal yol; Minimum Yürütme Süresi (MET) planlaması; Güve Alevi Optimizasyonu (MFO); Ad hoc Ağ; Dinamik Kaynak Yönlendirme (DSR) yaklaşım.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

MANETs:	Mobile Ad hoc Networks
QoS:	Quality-of-Service
DSR:	Dynamic Source Routing
IETF:	Internet Engineering Task Force
MET:	Minimum Execution Time
MFO:	Moth Flame Optimization
CPU:	Central Process Unite
WLAN:	Wireless Local Area Network
PANs:	Personal Area Networks
PDAs:	Personal Digital Assistants
PSR:	Proactive Source Routing Protocol
GSR:	Global State Routing
OLSR:	Optimized Link State Routing
DSDV:	Destination Sequenced Distance Vector
WRP:	Wireless Routing Protocol
FSR:	Fisheye State Routing
AODV:	Ad hoc On-demand Distance Vector
RREQ:	Route Request
RERR:	Route Error
ABR	Associativity-Based Routing

ZRP:	Zone Routing Protocol
ZHLS:	Zone-based Hierarchical Link State
GPS:	global position system
GA:	Genetic algorithm
ACO:	Ant colony optimization
ABC:	Artificial bee colony
MAC:	medium access control
ES:	evolution strategy
NSGA-II:	Non dominated Sorting Genetic Algorithm version II
BIP:	broadcast incremental power
MP-DSR:	multi-path DSR
EMP-DSR:	Enhanced multi-path DSR
NP:	nondeterministic polynomial time
LP:	Linear Programming
DE:	differential evolution
SA:	simulated annealing
VANETs:	vehicular Ad Hoc networks
NS-2:	Network Simulator version 2
PDR:	packet delivery ratio
E-to-E:	end to end
GrAnt:	agreed ant colony

DTNs:	Disruption Tolerant Networks
M-OLSR:	Modified-OLSR
NRL:	Network Routing Load
A E-E D:	Average End-to-End delay
EH- Ant–DSR:	Enhanced Ant DSR
OSI:	Open Systems Interconnection (OSI)
RREP:	Route Replay

CHAPTER 1
INTRODUCTION

1.1 Preliminaries

These days, due to the increment in the advancement of wireless communication technology and the popularity of personal communication devices and portable communication devices, wireless communication networks have become a popular communication network. Unlike wired networks, wireless communication networks able to provide users the roaming property and they can move freely without any restriction to the direction, and at the same time, they will stay in connection status with the network. However, in some situations due to the unreliability of the local infrastructure or the absence of the infrastructure, the initialization of the wireless network will become difficult. In such conditions, the better solution is to use Mobile ad hoc networks (MANETs) (Mohapatra and Krishnamurthy, 2005; Ilyas, 2003).

MANETs belong to the infrastructure-free wireless networks and can be defined as a group of distributed and autonomous mobile nodes which form a temporary network, each node in this network can move freely and randomly in any direction to provide MANETs with dynamic and unstable topology (Conti and Giordano, 2014; Simaremare et al., 2015; Prasath and Sreemathy, 2019). Furthermore, each node has a wireless trans-receiver facility and can communicate indirect manner with the remainder of the nodes if they are located within the communication range of each other or they might be communicating indirectly through intermediate nodes if they are not placed within the communication range, in such cases, the communications among nodes are performed without depending on a pre-existing infrastructure such as access point or base station (Prasath and Sreemathy, 2019). Therefore, a centralized administrator is absent in MANETs. It can be considered as a decentralized structure where all nodes work together to handle the data transmission between the source and the destination (Abolhasan et al., 2004; Manickavelu, and Vaidyanathan, 2014). These previous characteristics have made MANETs useful in many applications, which include battlefield communications, disaster areas, health care, mobile conferencing, environment monitoring, and so on (Perkins, 2001; Vasiliou and Economides, 2006; Kannhavong et al., 2007).

To provide an effective communication process in such MANETs, The routing mechanism which is responsible to forward data packets between the sources and the destination needs to provide the optimal route. The performance of the routing algorithm is an essential factor in MANETs and it affects the global performance of MANETs. Based on the mechanism used to discover the route, the routing algorithms are generally divided into three classes:

- The proactive routing approach, which is also called a table-driven routing mechanism, is the method where every portable hub (node) stores the gathered data about the dynamic topology as the consistently refreshed routing tables (Prasath and Sreemathy, 2019). In this sort of routing strategy, there is no necessity to discover the paths for every data bundle sending and they are increasingly productive when the system has relative hubs at the stationary condition and relative substantial traffic (Harrag et al., 2019).
- Reactive routing strategy, in this strategy of routing, only at the time the source hub owns data bundle to forward, the routing mechanism starts searching for the path and builds up the connection to use it to forward the packets (Robinson et al., 2019; Nasipuri and Das, 1999). This kind of routing method is based on flooding the network with route request packets (Zhang et al., 2018; Pathak and Jain, 2017; Ghaffari,2017).
- Hybrid routing class, which based on combining the benefits of both aforementioned routing methods.

1.2 Motivation

As stated in No Free Lunch theory that there is no certain algorithm able to solve all the optimization problems (Wolper and Macready, 1997; Shah et al. 2018), this means that a specific optimizer can achieve good performance under one situation may fail to achieve these good results in other situations. Therefore, a new optimization algorithm can achieve better results than the existing optimization algorithms in a specific scenario. These previous statements represent the motivation of this work, Here, the research proposes a solution to routing optimization issues in MANETs by utilizing data packets scheduling and meta-heuristic bio-inspired optimization algorithms to provide an efficient and optimal routing algorithm. The suggested routing approach considers more parameters to enhance the performance of the routing approach and provide optimal route solutions. The results of the simulation show that the created routing algorithm provides better Quality of Service (QoS) through less energy consumption, less delay, and less overhead, meanwhile, it provides high packet delivery ratio and throughput.

1.3 Problem Definition

The Dynamic Source Routing (DSR) protocol has some disadvantages such as its reliance on the minimum hope count parameter to select the path without considering any other factors that affect the routing algorithm performance like energy consumption, residual energy, link stabilities, routing overhead, and so on. Furthermore, due to the inefficient route discovery mechanism which is based on flooding, DSR provides a low packet delivery ratio in high mobility environments, long delays, high routing overhead information, and very high energy consumption. Therefore, this research work aims to enhance the typical DSR performance by utilizing a unique hybrid optimization technique based on data packets scheduling and meta-heuristic optimization method. The applied hybrid optimization mechanism is based on the Minimum Execution Time (MET) packet scheduling method and Moth Flame Optimization (MFO) scheme to provide the optimal route.

1.4 Thesis Framework

This research work is introduced under four chapters as follows:

- **Chapter-2**: is dedicated to MANETs in which we investigate the ad hoc networks, essential concepts related to MANETs, characteristics, challenges, and applications of MANETs. The last side of this chapter presents the routing methods.
- **Chapter-3:** is covered the state of the art of meta-heuristic bio-inspired optimization approaches utilized in MANETs to solve resource optimization. it also provides a review in detail about optimizing routing methods.
- **Chapter-4:** is devoted to the proposed hybrid optimized routing algorithm. The hybrid optimization mechanism is based on minimum execution time (MET) as a packet scheduling method and Moth Flame Optimization (MFO) which is integrated with the DSR protocol to provide the optimal route. A further detailed explanation about DSR, MET scheduling, MFO scheme, and proposed MET-MFODSR will be introduced in this chapter.

- **Chapter-5:** it concentrates on the simulation environment implementation of the proposed hybrid optimized MET-MFODSR algorithm. The simulation results will consist of different simulation environment by comparing the existing methods with the proposed MET-MFODSR method
- **Chapter-6:** provide a conclusion of the research work and draw the possible way to extend the introduced work as a scope of future work.

CHAPTER 2
MOBILE AD HOC NETWORKS

2.1 Introduction

Nowadays networks are existing almost in every place and many items of the modern world. Networks in a simple manner can be defined as a group of hardware components with installed software materials which interconnected the components using channels allowing them to exchange information and share the resources.networks can be classified according to their various attributes such as the medium typically used to transfer the packets, topology structure and so on (Onyemelukwe, 2013).

Networks are based on the communication medium used to exchange and transfer packets mainly classified into wired networks and wireless networks. In wired networks, the network components are interconnected via a physical link such as (Ethernet, optical fiber cable, coaxial cable), on the other hand, wireless networks are based on using signals and radio waves as a wireless medium to allow signal propagation and interconnect hardware components.

The popularity of wireless communications between mobile devices has increased and it becomes widely spread in all fields in our life. The recent technical progress in integrated circuits, transmitters, computing, and communication equipment participated in the spreading of the wireless technological facilities. Twin different methods used to provide wireless communicating among two mobile nodes; the first method is based on using the network infrastructure to transfer data among nodes. The main issues in the infrastructure-based wireless networks are fading and handover. Furthermore, such type of networks is restricted to be available where the infrastructure of the network exists. The second method is based on networks in which one of their advantages is not relying on pre-existing infrastructure. Therefore, wireless networks can be divided based on their architectures into infrastructure-based networks and infrastructure-free networks which are also named MANETs.

2.2 Ad-Hoc Network

It is an aggregation of mobile hubs (nodes), that frames a temporal network in the absence of the central controller or any other conventional aid devices as in classical wireless networks, these hubs can transmit in limited range and, therefore, every hub looks for the help of its neighboring hubs in sending packets and henceforth the hubs can work as the hosts and routers. Hence a node may send packets between different hubs and run client applications (Onyemelukwe, 2013; Harrag, 2018; Conti and Giordano, 2014; Simaremare et al., 2003; Prasath and Sreemathy, 2018).

Fig.1 illustrates a MANETs with a possible scenario of the communication process between their mobile nodes. It can be observed in Figure 3.1 that there is no central administrator and the nodes cooperate to handle the communication process. Assume that node A wants to communicate with node D, in this situation D is located in the outside coverage range of node A which is represented in this figure as a dashed line circle. Therefore, node A and node D cannot communicate directly. To exchange their packets, intermediate nodes (B and C) participate in the communication process and behave as wireless routers to send the data between A and D, because node B and node C exist in the coverage range of node A and D respectively (Onwuka et al.,2011).

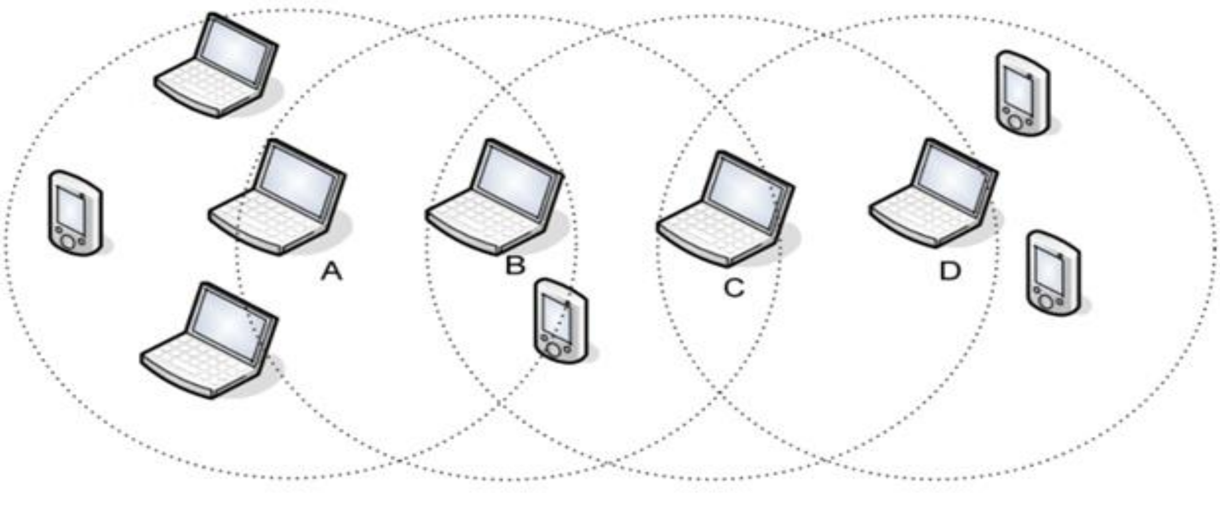


Figure 2.1: MANETs with a possible communication scenario (Harrag, 2018)

2.3 Features of MANETs

MANETs are self-organized and adjustable in the form of temporally and dynamic network topology without any aid of central administration. Despite that, MANETs have some similar properties of classical wired networks; they still own their unique features inherited from their wireless shared medium nature. MANETs have the following characteristics:

1. *Mobility of nodes and dynamic topology*

In MANETs, as a consequence of the mobility characteristic, mobile nodes move freely and randomly in a nondeterministic pattern. This mobility model leads to create dynamic and unstable topology structure. Furthermore, the wireless natures with the mobility feature of MANETs make them easy for deployment under any kind of environment.

2. *Resource limitation*

In MANETs, the mobile nodes are called thin clients and that's because of their characterization by scarce resources, which include limited memory, bandwidth, and Central Process Unit (CPU) ability (Onyemelukwe, 2013). Moreover, using wireless links in MANETs provide less capacity and throughput in comparison with infrastructure-based network due to the impact of noise, fading, and multiple access schemes. Also, another effect of the relative low link capacity is the congestion which occurs when data traffic reaches or exceeds the capacity of the network (Agrawal and Zeng, 2011).

3. *Multi-hop network and multi-functions of nodes*

Mobile nodes in MANETs can interact directly if they are located within the transmission range of each other or they communicate indirectly via intermediate nodes which act in this situation as a router to provide multi-hop MANETs (Yi, 2008). Besides, in such multi-hop MANETs, nodes act as a host and router component to forward data packets .this express those nodes in MANETs have multi-functions (Harrag, 2018).

4. *Energy constrained*

In MANETs, the mobile hosts have a limited battery power which can impact the survivability of the network since the links will be disconnected when these mobile hosts consume their battery. Therefore, there is a need to consider the consumption of energy of nodes as a significant factor to keep the connectivity and prolong the network lifetime (Perkins, 2001; Taha, et al., 2017).

2.4 Advantages of MANETs

The increased attention in MANETs is coming out form their practicality and advantages which can be enumerated as follows (Onyemelukwe, 2013; Helen and Arivazhagan, 2014) :

1. ***Easy and fast deployment***

In comparison with Wireless Local Area Network (WLAN) as an example of wireless networks, MANTEs are more suitable and easier for deployment and require fewer manual input specifications. Also, MANTEs can be directly installed in-flight whenever required.

2. ***Low cost of installation***

MANETs are the infrastructure-less wireless networks that do not need infrastructure-based wireless components such as base station (access point), wireless routes, or switches. This will make MANETs has less deployment cost.

3. ***Flexibility and dynamic structure***

The flexibility and dynamic topology structure of MANETs due to mobility make them easy to install anytime anywhere on the fly with quicker communication and easer administrative.

2.5 MANETs Application

Due to MANETs aforementioned advantages, they can be utilized successfully in various applications, these applications extended from uncomplicated civilians and commercial usage up to complicated significant risks disaster services and military field (Sharma et al., 2012; Yi, 2008). This part introduces the significant applications of MANTs in various domains such as civil and commercial, disaster area, and military field operations.

1. **Commercial and civil applications**

The Personal Area Networks (PANs) and vehicular communications in an urban area are two developing wireless networks schemes which in a short time have been part of daily life. PANs can be created between several mobiles (and fixed) devices basically in an ad hoc way. For instance, at the campus of the university, students can create a limited number of workgroups to share documents and to exchange presentation slides, results, and so forth. At conferences, members can network their Personal Digital Assistants (PDAs) or laptops to exchange files and other demanded service. Furthermore, in the vehicular communication case, wireless communication within short distances can be utilized to monitor and control the mechanical parts of vehicles. Also, another useful application of vehicular communication is provided communications between vehicles on the track.

2. *Disaster area*

MANETs can play a significant role in rescue operations during disaster areas and emergency case situations (Harrag, 2018; Onwuka et al.,2011; Monares et al.,2011; Lenert, 2005). In such environments, there is a possibility that the typical infrastructure-based wireless networks to be destroyed or inaccessible due to natural disasters. The rapid initialization feature of MANETs under these circumstances can be utilized to provide quick connectivity and information exchange. For example, police and firemen vehicles teams can stay in connection and able to share information rapidly when they create an infrastructure-free ad hoc network. The main factors that promote MANETs in such cases are self-organization ability with less routing overhead, free of fixed and central administrative infrastructure, freely movements and mobility, as well as the inaccessibility of traditional infrastructure wireless networks.

3. *Military field operations*

The source of developing mobile ad hoc networks for military purposes and battlefield operations networks, which makes the soldiers able to perform their communications at any time they required and in any event they needed (Sharma et al., 2012). Furthermore, using ad hoc networks to establish a communication process between independent organizing vehicles can be also possible in such environments. The lifesaving operations can be performed possibly using ad hoc networks through communications with the head office.

2.6 Routing Mechanism in MANETs

In MANTEs, the Routing process is performed by network layer task and can be defined as the mechanism of obtaining the path to transport the data information from the sender to the target (Prasath and Sreemathy, 2018; Taneja and Kush, 2010; Malwe et al.,2017). The effective performance of the routing schemes is a significant factor in MANETs and can influence the QoS indexes, which include the throughput, delay, packet delivery ratio, etc.. The effective routing algorithm aims to provide desired QoS requirements by reducing the latency, energy consumption, and routing overhead .similarly it should be able to achieve high throughput and packet delivery ratio (Prasath and Sreemathy, 2018; Simaremare et al., 2015). despite existing various proposed routing methods, none of them able to meet the whole requirements. The conventional existing routing algorithms can be placed into three classes, that's proactive table-based, reactive on-demand, and hybrid routing methods (Prasath and Sreemathy, 2018; Taneja and Kush, 2010; Malwe et al., 2017; Kannhavong et al., 2007; Chlamtac et al., 2003; Boukerche et al., 2011; Royer and Toh 1999; Shenbagapriya and Kumar, 2014).

2.6.1 Proactive routing schemes

They are also called a table-driven routing mechanism, in such a case of routing scheme, every node caches the gathered information regarding the active paths in the set of the regularly updated routing tables (Prasath and Sreemathy, 2018). In proactive routing methods, it is unnecessary to obtain the paths for each packet transporting process.furthermore; they are more effective to apply within the network has nodes with approximately stationary status and the data traffic is approximately heavy (Harrag et al., 2019). However, the proactive routing methods cost the wireless medium a wide range of the available bandwidth, takes further storage space, and costs the nodes more power to update the table of routing information (Harrag et al., 2019; Robinson et al., 2018). In aneja and Kush (2010) Proactive Source Routing Protocol (PSR), Global State Routing (GSR), Optimized Link State Routing (OLSR), Wireless Routing Protocol (WRP), and Fisheye State Routing (FSR) were presented as typical proactive routing models.in general, proactive routing methods can be categorized into distance vector proactive routing approaches and link-state proactive approaches.

1. ***Distance vector proactive routing methods***

The path selection in this approach is based on the cost of the transmission link amongst the sender and all other nodes belong to the network. Each node presents its direct connecting links and the costs associated with their communication link information and the costs of information obtained from the remaining hubs. Destination Sequenced Distance Vector

(DSDV) is an example of distance vector proactive routing methods (Perkins and Bhagwat, 1994), in which the hop count to the target node is used as the parameter cost. In this method, the routing information is broadcasted into the network including the sequence number, which is created by the target node. The purpose of using the sequence number is to avoid a typical problem in DSDV called routing loop. DSDV responds to the changes in the topology structure using full dump and incremental as updating packets. Full dump packets aim to transfer all obtainable routing information from the present node to another one whereas the changed information from the last full dump will be carried using the incremental packets. The purpose of these used packets is to weaken the overhead and minimize the update delay. despite that, DSDV still suffering from large overhead resulted from large overhead due to the huge number of periodical updating information, which leads to unscalable DSDV (Harrag, 2018).

Another example of a distance vector-based protocol model is WRP, in this method, every node holds four kinds of tables: these tables include distance table, message retransmitting table, routing table, and link cost table. In this routing approach, the previous information together with a number of the sequence is used to prevent routing loops issues. However, WRP suffers from the bandwidth consumption overhead and high usage memory as a result of maintaining high information in every node (Harrag, 2018).

2. *Link state proactive routing methods*

They exchange a huge amount of information between nodes to offer a comprehensive view of the network and create a routing structure to forward the packets.in the same way of distance vector-based proactive protocols, link-state methods also consume a large bandwidth due to the routing control information which leads to high routing overhead. FSR is a sample of link-state routing methods, in which the topology structure is maintained at every node by sharing the information about link-state among neighbor nodes (Clausen and Jacquet, 2003; Perkins and Bhagwat, 1994). But the packets related to the link state will not broadcast and only shared periodically with their local neighborhood nodes. This leads to reducing the control routing overhead. Furthermore, FSR uses the fisheye mechanism to reduce periodically updating packets in which the nodes located in smaller ranges are updated more often than those nodes placed further away. FSR is depending on the special situation of FSR called GSR in which the scope is one. The benefits of FSR including minimizing the flooding packets as well as the routing process is more precise concerning the nodes near to the target node, which making FSR appropriate in a dense environment. On the other hand, FSR suffers from the probability of inaccurate path selection due to a slower update mechanism for far away nodes.

Another sample of the link state reactive routing method is optimized link state routing (OLSR) (Clausen and Jacquet, 2003). In this routing method, every node floods regularly a list of one-hop surrounding neighbor nodes. OLSR broadcast partly links information by using multipoint relays which include every two-hop surrounding neighbor nodes. For this reason, the rate of link state information will be minimized by obtaining the complete structure of the topology. On the other hand, using a one-hop neighbor list flooding mechanism is not suitable enough in MANETs as this leads to increasing routing overhead in widespread networks. with this, in wireless mesh networks, there is a proposal of combining the FSR with OLSR (FSR-OLSR) to obtaining a routing approach called (F-OLSR) (Johnson and Maltz, 1996). Haas and Pearlman (2001); Joa-Ng and TaiLu (1999) show in their evaluation that OFLSR provides a higher packet delivery ratio and less arrival delay in comparison to AODV as a reactive routing method. On the other hand, OFLSR shows higher routing overhead than AODV.

To sum up, the majority of the table-driven routing methods are not adequately scalable as a result of an extra amount of routing overhead. Regarding the delay and the efficiency of packet delivery, proactive routing schemes are better than those reactive methods by utilizing the additional routing overhead amount. Many studies have been conducted to minimize the routing overhead and resulted in hierarchical routing as a considerable and success routing method similar to OLSR. However, in this type of routing method assigning representing nodes such as multipoint relays in the case of OLSR or head of cluster in some hierarchical methods can be a disadvantage due to the mobility environment. Thus, it causes extra routing overhead in the network at the same time mobility is one of its features. Furthermore, proactive routing strategies maintain unnecessary information about all the links which the majority of them not utilized. Therefore, reactive routing approaches can be viewed as more appropriate in MANETs.

2.6.2 Reactive routing approaches

In this approach, if any node needs to exchange a bundle of data to the target, at that moment only, the source node commences checking and discovering the route (Prasath and Sreemathy, 2018; Kannhavong et al., 2007; Robinson et al., 2018; Nasipuri and Das, 1999). The source floods the network with route research message to reach the destination, and when the target received the route inquiry message, the route reply will be sent from the destination back to the sender in a reverse way (Zhang et al., 2018; Pathak and Jain, 2017; Ghaffari,2017). This scheme of routing methods does not involve a frequent route table updating as the path may vanish or is no further needed, these routing methods have minimal control routing overhead, and it can be applied in high mobility environment or high traffic data situation (Taneja and Kush, 2010; Harrag et al., 2019). At the same time, this routing policy shows high latency due to the route setting mechanism (Prasath and Sreemathy, 2018; Harrag et al., 2019). DSR protocol (Johnson and Maltz, 1996), temporally-ordered routing algorithm (TORA) (Park et al., (1998), and Ad hoc On-demand Distance Vector (AODV) has been suggested as a typical reactive routing approaches (Perkins and Royer, 1999). Generally, The reactive routing methods can be divided into two classes: source routing and hop by hop routing.

1. *Reactive source routing methods*

In this kind of reactive routing, the routing information details are only maintained by the source node. The path of the transmitted packet between the source and the target will be added at the source as a header of the packets. The intermediate nodes in this routing scenario have no awareness about the path to the target node and they only do packet forwarding based on the header information. In this reactive routing scheme, the routing overhead is decreased because of no need to maintain routing information in intermediate nodes. However, the route breakage probability could be increased as the route in a wide range area gets longer or in the case of a higher level of mobility. Furthermore, the routing overhead information which included a header can also impact the performance in the case of wide extends networks. Based on previous disadvantages, it is the reactive source routing methods are not well scalable. One example of the reactive source routing protocol is DSR (Johnson and Maltz, 1996). DSR is an uncomplicated source reactive routing method that works on two phases: route discovery phase and rout maintenance phase. Both strategies work in a purely reactive manner. This means that as long as there the network topology stable, the result will be not any added control information. DSR advocates multiple paths that aid to reduce the delay once the currently used path is broken. Besides the source started flooding Route Request (RREQ) messages, each one of the mobile nodes caches in each information packet the embedded routing overhead information which leads to increasing the possible number and refreshed routes. When link statues on the path become disconnected, a message of Route Error (RERR) will be sent in a back way to notify the source, once the source received the (RERR) packet, the disconnected path is eliminated and other alternative routes will be chosen or route discovery process will be initialized. Based on previous behavior, DSR is providing less routing overhead, furthermore, DSR shows better performance compare with AODV regarding the delay and routing overhead in low mobility and a low number of source scenarios. On the other AODV shows better performance than DSR with respect delay but routing overhead still higher under high mobility and number of sources environment, which can be more similar to real-world applications.

Another example of reactive source routing methods is the Associativity-Based Routing (ABR) method (Toh, 1997) .it is a special kind of reactive source routing strategy as it applies similar DSR route discovery process but at the same time it maintains local routing information as in AODV, also ABR concentrate on the route stability factor instead of having many backup paths as in DSR. Furthermore, the route selection in ABR is based on the associativity tick metric provided by each node in the form of periodical beacons showing the association stability level of each mobile node. In the route discovery stage, the associativity tick is added to the header with addresses to obtain the best route based on all associativity ticks of up-stream mobile nodes. ABR requires route recovery when link failure occurred because ARB does not use route backup. Although the route recovery is established locally, it will lead to more routing overhead as well as a longer time delay.

2. *Reactive hop-by-hop routing protocols*

In this routing approach, the routing information is maintained locally at every node. The destination address is stored with the data packets as a header and the intermediate nodes will check the routing table to forward the data to the designated target. The high adaptively of the route represents the advantage of this method and this is because the nodes can respond to network topology change quicker than the end-to-end way. However, to maintain the routing data at every node more routing overhead and resources are needed. AODV is an example of a reactive hop-by-hop routing method (Perkins and Royer, 1999). The classical AODV uses the route discovery technique by broadcasting route request messages. When the route request reaches the destination, the route replay message will send back toward the source by using the reverse-path which previously obtained by the route request message.in AODV a blacklist is used to prevent the usage of unidirectional links obtained by the route request message but can not be used by the route replay packets. Furthermore, the forerunner list will be maintained to track the upstream mobile node which is using this path. If a route breakage occurs, then a route error message will be broadcasted until it arrives at the source node or the mobile node that has an empty forerunner list. When the source gets the route error message, the route reconstruction process starts again by repeating the route request and route replay processes. In terms of the route reconstruction process, rather than re-initializing the route discovery process the local route repair characteristic in AODV is used to minimize the delay. also, another characteristic of AODV which enables the intermediate mobile nodes to react to the RREQ can be selected to further reduce the delay.

In summary, the reactive routing methods normally need less routing overhead in comparison with the proactive routing methods because they only keep the required routing information.it was noticed that DSR provides less routing overhead, longer lifetime of the node, and higher throughput in comparison with OLSR. On the other hand, the good point for OLSR is the ability to provide less delay which is the common benefit of proactive routing approaches. Based on that, it can be observed that the reactive routing methods are generally more appropriate than the proactive methods unless the specific application needs an extremely little delay. In terms of different reactive routing methods comparison, AODV shows higher adaptivity than DSR because it provides less delay and higher throughput during a high mobility environment.

2.6.3 Hybrid routing approaches

Hybrid routing approaches are based on mixing the advantages of the proactive and reactive routing schemes to establish better performance (Prasath and Sreemathy, 2018; Boukerche et al., 2011; Harrag et al., 2019). The philosophy of such a routing method is to apply the proactive method to maintain the routes within the region whereas using the reactive method to maintain the paths which link the different regions (Boukerche et al., 2011). In hybrid routing methods, the routing overhead is minimized as the inefficient control information used in the proactive method is exclusive only inside the zone whereas the less routing overhead resulted from reactive is applied to connect efficiently each zone. Zone Routing Protocol (ZRP) (Harrag et al., 2019) and Zone-based Hierarchical Link State (ZHLS) (Robinson et al., 2018; Perkins and Bhagwat, 1994), are models of the hybrid routing methods.

ZRP is an example of a hybrid method of routing so that proactive routing overhead is reduced by applying the proactive routing strategy only inside the zone. ZRP uses the broadcasting to discover the route to any node located outside of the zone, which also results in decreasing the number of flooding packets. During the broadcasting process, the node at the border of the current region will forward the route request. Once the border node receives the route request message, it will check out the routing table in its region and then transmit back the route replay message when it knows the path to the destination or otherwise continues broadcasting mechanism. The radius of the routing region is a significant factor in ZRP and also represents a disadvantage for it. This radius has to be selected carefully according to features of the network, because when the radius is selected to be very large, ZRP acts more likely in a purely proactive manner. On the other hand, when the radius is very small, ZRB acts more likely in a purely reactive manner. In two situations, ZRP has lost its benefits of scalability and minimized overhead.

As another example of a hybrid method of routing is the ZHLS (Robinson et al., 2018; Perkins and Bhagwat, 1994).it applied zone hierarchical link-state routing method, which also utilizes position information obtained by the global position system (GPS). unlike ZRP which determines overlapped regions, ZHLS uses the position information to divide the network into non-overlapped regions and allocate node ID to each one of the nodes and region ID. The hierarchy structure of ZHLS is composed of two levels, that's node level and area level.in ZHLS, there is no existence of cluster head as the regions are predefined to their position information. Therefore, despite ZHLS is a hierarchy structure routing method, bottlenecks or single-point failure can be prevented. The ZHLS routing strategy consists of two phases like ZRP and these two phases include intra-region proactive routing while interregion reactive routing. Thus, the same advantages in ZHLS can be accomplished. Also, The ZHLS has a fixed region position. When the source has the ID of the destination node and its region ID, even though the link disconnected, ZHLs able to provide an alternative path to the destination with lower routing overhead in comparison with the reactive routing methods.at the same time, the fixed region position can be considered as disadvantages in ZHLS because it needs to pre-programming prior usage.

To sum up, hybrid routing methods are based on the idea of integrating proactive and reactive routing methods to achieve more scalability. Lower overhead and less delay can be obtained in hybrid routing methods even in the case of a widespread network. However, hybrid routing methods need appropriate parameters set, such as the radius of the routing region in the case of ZRP or pre-programming for fixed region location purpose in the ZHLS method for a single network.

CHAPTER 3
META-HEURISTIC ROUTING ALGORITHMS IN AD HOC NETWORKS

3.1 Introduction

The issue of finding the path in MANETs has been taken place in many research works that were conducted related to the MANETs area. Despite many routing methods are introduced in the literature with their features, they still have some weakness. This chapter concentrates on how natural bio-inspired meta-heuristic algorithms can be used in the routing process of MANETs to establish an automatic selection of the optimal routing (Parpinelli and Lopes, 2011; Boussaïd et al., 2013; Harrag, 2018; Yang et al.,2010; Xiao-Yan and Yang, 2013).

In the last ten years, the natural bio-inspired algorithms called metaheuristic algorithms were widely applied in MANETs. The main reason behind this extension was their effectiveness and application as stochastic optimization methods to MANETS issues which usually difficult to be addressed using classical techniques (Elizarraras et al., 2014; Harrag, 2018; Lafta and Al-Salih, 2014).

3.2 Bio-inspired meta-heuristic optimization algorithms in MANETs

In modern society, communication networks have played a significant role in daily life in many fields. before thirty years, no person could imagine the tremendously successful and the participating of mobile communication devices and they are succeeded such as smartphones, PDAs, and tablets in daily life. The progress in networking technology is more rapid than information technology systems; the smaller devices possess their communication abilities. However, the present communication systems are not suitable or effective in such an environment of heterogeneous MANETs. Therefore, Self-independent strategies which able to manage the dynamic environment, scalability, heterogeneity, link failures, and so on are required (Lopez et al., 2014; Harrag, 2018).

It can be seen there are similarities between MANETs and biological systems in many aspects such as cooperation behavior, self-organizing, seeking stability, recovery from failure, resources minimizing, and so on. The majority of these biological systems accomplished this pattern of behavior after millions of years of development. Therefore, there are various researchers have worked to develop algorithms derived from nature as a great source of inspiration to address many problems effectively. For an instant, in the literature, it can be seen how natural bio-inspired algorithms have been extensively utilized in network designing and optimization (Dressler and Akan, 2010) [9]. An overview of some well-known bio-inspired meta-heuristic algorithms used in ad hoc networks is presented in the next sections.

1. *Genetic algorithm (GA)*

It was the first introduced evolutionary-based algorithm in the literary work, it has been created based on the natural mechanism of biological evolutionary throughout reproduction (Elsayed, 2016).GA was developed by Holland and extended within the period of the 1960s and 1989. It is widely used to solve nonlinear and complex problems in real life (Elsayed, 2016; Holland 1992).

2. *Particle swarm optimization*

PSO is a meta-heuristic global optimization algorithm which originally designed in 1995 by Kennedy and Eberhart (Elsayed, 2016; Eberhart and Kennedy, 1995). It is one of the common natural-based swarm intelligent optimization algorithms which originally implemented based on the social behavior of birds swarm (Elsayed, 2016; Xue et al., 2014). [10,13]. PSO was successfully applied to obtain optimal solutions in any field related to feature selection and optimization (Chakraborty, 2008).

3. *Ant colony optimization (ACO)*

ACO is a natural bio-inspired meta-heuristic optimization algorithm developed at the beginning of the 1990s to solve hard combinatorial optimization problems (Dorigo, 1992; Dorigo et al. 1991; Dorigo et al. 1996; Dorigo and Blum,2005). ACO was originally inspired by the food searching process of real ants. The process followed by ant colonies in nature is utilized as an artificial ACO algorithm to solve hard problems in various fields (Dorigo and Blum,2005).

4. ***Artificial bee colony (ABC)***

ABC is an optimization method introduced in 2007 by Karaboga (Elsayed, 2016; Karaboga and Basturk, 2007). ABC algorithm is inspired by honey bees' behavior during food searching.in this algorithm, there will be a kind of bees named employer which try to discover the source of the food and make advertisements .then the other type of bees called onlooker will follow those employers and the bee scout will fly automatically to discover better sources of food (Elsayed, 2016; Akbari et al. 2010).

5. ***Moth flame optimization (MFO)***

MFO is a type of the recent-implemented meta-heuristic optimization algorithms introduced by Seyedali Mirjalili in 2015 (Mirjalili, 2015). It is inspired by moths navigation strategy, which is also named as transverse orientation. In this navigation strategy, moths hover in a straight path by keeping a constant angle regarding the distant moon. it is an efficient way to travel in far distances with a straight line (Mirjalili, 2015; Shehab et al. 2019; Shah et al. 2018). The mathematical representation of s this behavior was named as the MFO.it is applied to solve many optimization problems in many fields.

3.3 Routing in MANETs based on bio-inspired methods

In MANETs, routing protocols are responsible to search and obtain a suitable path. As a result of the absence of a central administrator, unstable topology, scarce resources, and decentralized structure of MANETs, the routing function will be a challenging task. Generally, there are two approaches to routing techniques that are proactive and reactive. The first method monitors regular changes in the topology structure; therefore, it will provide immediate and ready routing tables, specifically when the topology nature is highly dynamic. On the other side, the reactive mechanisms only find a path when it is required. Some hybrid methods have also been suggested based on combining the advantages of both proactive and reactive strategies. Boukerche et al. (2011) provide a survey about routing algorithms in wireless MANETs.

Due to the routing task complexity in MANETs, there are various research works presented in the literature trying to establish effective packet routing to the target node by using bio-inspired methods. Some of these researches work suggesting routing approaches using ant colony optimization methods, this is because of the possibility to implement online together with local knowledge, which makes it suitable to MANETs (Harrag, 2018). Various surveys cover ant-based routing approaches (De Rango and Socievole, 2011; Singh et al, 2012). The following section presents a vast review of applying bio-inspired optimization algorithms to obtain the optimum configuration parameters appropriating a particular protocol.

3.4 Literature review on meta-heuristic optimized routing algorithms

The present section provides a literature survey of the usage of meta-heuristic optimization methods for optimal routing appropriating a particular protocol in ad hoc networks during approximately the last two decades time period, which presented in the following manner:
Montana and Redi (2005) have investigated applying GA to perform automatic parameter selection in the MANETs. The strategy was examined for hand-tuning under a complicated and realist environment. The simulation outcomes showed that automatic parameter adjustment based on the suggested method outperforms the hand-tuning method under all investigated situations. Furthermore, the proposed approach proved that no individual signal set of parameters can provide the best achievement which shows that the parameters setting problem is a multi-objective type.

A self-configuration feature of GA and its ability to provide network neighbor information state was utilized to develop an algorithm, which aimed to enhance clustering based routing mechanism. The purpose of applying GA to enable quick and efficient routing information exchange between nodes so that adapt MANETs structure by reducing link disconnections and rising lower medium access control (MAC) layer overhead. The author's simulation results indicated that with GA, the MAC protocol operation is optimized and decreasing the number of the clusters respectively cluster heads, additionally, clusters loads are also more evenly balanced. (Al-Ghazal et al. 2007).

The broadcasting mechanism in MANETs was studied by view it as a multi-fitness optimization problem based on PSO and evolution strategy (ES) with the Non dominated Sorting Genetic Algorithm version II (NSGA II).in this work, a predefined network topology with Mall scenario which simulates the shopping mall is used to examine how these two algorithms able to find the optimal front of Pareto. The parameter selection is based on using the minimum bandwidth, higher coverage, and fewer makespan as objectives. The results

proved that both algorithms able to obtain Pareto optimal front with respectable accuracy (Perez-Perez et al. 2007).
Wu et al. (2008) introduced a solution for the lowest power broadcast issues in MANETs. The proposed solution is based on applying permutation-encoded GA to provide an identical broadcasting tree. The proposed method outperformed the existing broadcast incremental power method.

Urrea et al, (2009) studied and compared different methods for knowledge sharing mobile agents in MANETs using GAs concerning random walk and hill-climbing methods in terms of node densities, number of generations, and speed in which GA runs. The simulation results indicated that all cases based on GA-based provide positive results in related establishing uniform nodes distributed over a geographical region.

Asl et al. (2009) introduced a new strategy to improve the multi-path DSR (MP-DSR) algorithm and called the introduced algorithm called Enhanced Multi-Path Dynamic Source Routing (EMP-DSR). This introduced approach has based the idea of combining the MP-DSR algorithm with the ACO method to provide reliability for data transmission. The results of the simulation proved that the EMP-DSR algorithm is performing better than the conventional MP-DSR algorithm. The reason behind that is EMP-DSR algorithm finds more reliable paths with shorted end-to-end time delay.

Hernández and Blum (2009) suggested applying an ant colony as an optimization method to solve a minimum energy multicast issue in static ad hoc networks. This fundamental issue can be considered NP-problem. The authors applied the ant colony optimization method when the nodes of the network used directional and omnidirectional antennas. Their simulation results of the proposed approach provided better performance than existing algorithms.

Yadu et al. (2010) proposed using the GA optimization method with Linear Programming (LP) to decide the range of the transmission of each node in the network so that that total energy consumption is optimized according to QoS constraints which are packet bandwidth and the maximum hop count.

Guo et al. (2011) suggested an enhanced and adaptable version of the PSO approach for a statistic ad hoc network wherein each link uses a similar frequency band to address the joint opportunistic power as well as the transmission rate allocating. The purpose is to obtain a configuration that reduces the overall consumption of the power whereas increasing the summation of whole source utilities.

Konak et al. (2011) utilized the PSO method for dynamic topology management in MANETs by identifying some mobile nodes members as agents that are moving in the search area to enhance the network connectivity. The authors suggest optimizing the motions and the positions of these members. The connectivity measurement is calculated based on the maximum flow model.

Toutouh and Alba (2012) have utilized the non-dominated sorting genetic algorithm II (NSGA II) as a multi-fitness function tool so that provide OLSR with efficient parameters which lead to QoS enhancement in OLSR. The introduced optimized algorithm shows a significant reduction in OLSR scalability issues maintaining reasonable rates of packet delivery. Also, the routing overhead is decreased, whereas the delivery time is shorted.

Toutouh et al. (2012) have analyzed using four types of meta-heuristic bio-inspired approaches which are PSO, differential evolution (DE), GA, and simulated annealing (SA). The goal is to establish an automatic optimum set which required for parameterizing the OLSR algorithm. The proposed methods were tested by defining a set of real vehicular Ad Hoc networks (VANETs) environments. The simulation results performed by Network Simulator version 2 (NS-2) shown that the optimized configuration version of OLSR enhanced the routing efficiency by establishing a higher packet delivery ratio (PDR), less routing load, lower end to end (E-to-E) delay.

Hsiao et al. (2012) introduced a novel method using the PSO approach to address the minimum energy broadcasting in an ad hoc network, which is classified as non-deterministic polynomial-time hardness (NP-complete hard problem). The goal was to decrease the power usage of entire nodes that form the network. The authors utilize the fast convergence feature of PSO for this purpose and suggested a local search which is enhanced r-shrink. The outcomes proved that the suggested method exceeds the existing approaches.

Vendramin et al. (2012) introduced an agreed ant colony (GrAnt) algorithm which derived from applying an ant colony optimization approach with a greedy transition principle. The GrAnt aims to obtain the highly promising transferring agents (nodes) in Disruption Tolerant

Networks (DTNs).The approach utilizing some information related to transferring candidates such as betweenness utility, social proximity, and degree of centralization to provide better connectivity of the traffic toward the destination.

Gutiérrez-Reina et al. (2012) suggested a framework for the topological structure of MANET depending on the distance between stationary nodes and the speed of mobile nodes. The framework is based on combining GA and NS-2 to establish an optimal solution. More particularly, the fitness function is provided by NS-2 and acts to guide the genetic search. The introduced approach has been investigated under the rail transport environment and the results indicate the feasibility of the introduced approach and the possibility of extending this framework for addressing related application scenarios.

Toutouh et al. (2013) investigated the energy-efficient issue of the conventional OLSR algorithm under the VANETs environment using parallel GA. The main goal of this work was to perform automatic exploring for energy-efficient OLSR configurations by paying attention to the consumed power of the nodes in VANETs, furthermore, considering the QoS level during the communications. Their experimental investigations indicate that a vital decrease in the consumption of power for the VANET mobile nodes is achieved with the proposed OLSR based on parallel GA. The power consumption was reduced on average to 40.2% in comparison with classical OLSR, and considerably better enhancement which is 77.54% were calculated under dense and large VANETs environment. Additionally, the proposed approach also showed fewer overloads and less time to deliver the packets.

Zukarnain et al. (2014) suggested Modified-OLSR (M-OLSR) which is based on using PSO with PLSR to obtain fine-tuned OLSR parameters so that be suitable for the VANETs environment. The simulation results showed that M-OLSR outperforms OLSR and other developed OLSR version in terms of low lost packets, LNR ratio, and end-to-end delay. Also, M-OLSR provides a high packet delivery rate.

Varshney and Katiyar (2014) proposed an approach to detect incapable and selfish (disobeying) nodes as well as to find the optimal route in the MANET system. They applied GA on the DSR protocol to discover misbehaving nodes and establish the optimal path. The results indicated a significant improvement in the DSR approach. Moreover, ACO was used

with DSR to provide guaranteed optimality of the discovered path and the reason behind that in some cases, the path founded by GA is not necessarily the optimal one.
Lobiyala et al. (2015) introduced an algorithm to provide competitive routing algorithm performance so that better QoS under VANETs scenarios. This algorithm is developed by using PSO with AOMDV to establish optimal parameter configuration. Their obtained results showed 37.05%, 1.96%, and 80.65%, reducing in Network Routing Load (NRL), PDR, and Average (E-E D) respectively.

Chatterjee and Das (2015) developed new Enhanced Ant DSR (EH- Ant–DSR) which is Ant Colony bio-inspired optimization-based DSR protocol. This introduced algorithm aims to discover an effective route by addressing link breakage and congestion problems. Their simulation results indicated that EH- Ant–DSR shows better performance for, PDR, routing overhead, route breakage, and energy-consuming.

Gautam et al. (2016) proposed using both GA and SA algorithms in hybridization form to improve the standard OLSR algorithm. The results of the simulation indicated that OLSR based on hybrid GA and SA provides better QoS requirements and communication effectiveness in comparison with classical OLS. The introduced method increase PDR to 100%, decreases E-to-E delay to < 2 ms, and NRL up to 15%.

Tareq et al. (2017) proposed Bee DSR (BEE-DSR) algorithm which relaying on applying the Artificial Bee Colony (ABC) algorithm on DSR to provide energy cost routes. BEE-DSR is used to search and obtain the optimal path with paying attention to the energy level of intermediate mobile hubs and hop distance. The results proved that BEE-DSR outperforms DSR and BeeIP protocols.

Harrag et al. (2018) introduced an enhanced version of ZRP and called PSO-IZRP which is based on applying PSO estimate zone radius. The purpose of using PSO to adjust ZRP by itself according to environmental status and by considering the size of the routing region of each node. The simulation results based on the NS-2 platform indicated the introduced algorithm provides better efficiency regarding the performance parameters in comparison with classical ZRP.

Shah et al. (2018) suggested a new clustering method based on using the MFO algorithm for VANETs. They named CAMONET and it provides optimal clustering for efficient transmission. The simulation results showed that CAMONET showed the efficiency of this method compares with other clustering methods which make it a finer clustering method under VANETs environment.

CHAPTER 4
PROPOSED ROUTING PROTOCOL BASED ON HYBRID OPTIMIZATION

4.1 Scheduling In MANETs

MANETs are introduced as infrastructure-free networks whereby mobile nodes form an impermanent network for instantaneous communication among mobile terminals without relying on existing infrastructure, which make MANETs useful in many fields. the nodes can take the role of the sender, intermediate router, or receiver terminal to provide single-hop based or multi hops based communication. However, due to the mobility feature which resulted in a dynamic topology nature, the process of route discovery needs to establish frequently. therefore, This will put a very high burden on each node due to the packet processing and routing establishment. the route discovery mechanism and packet forwarding process need to be selected carefully to provide an optimal route with the best possible packet transferring and for this purpose, the scheduling method can play a significant role to accomplish these objectives. (Sufian et al. 2018) . In this work, scheduling terms used in MANETs to denote packet scheduling which concerns which packet is assigned to node among other reaming waiting for packets in the queue. (Sherin and Anita,2018).

In MANETs, data bundle flow through intermediate router nodes to reach the target, when any node receives forwarded packets, it starts serving only one of them while the remaining flow packets will be stored in the queue. The scheduling method (scheduler) is deciding which packet will be served between all the reaming packets (Kanellopoulos, 2019). The basic distinction in implementing packet scheduling mechanisms in MANET structure is that rapid dynamic topology and not whole nodes can interact with each other directly (Kanellopoulos, 2019).

Packet scheduling mechanisms are vital to ensure QoS provision by increasing the rate of packet delivery, throughput, and minimizing delay (Enzai et al., 2010; Kanellopoulos, 2019). Therefore, Scheduling algorithms need to consider QoS matrices such as PDR, throughput, packet E-E D, and distance to transverse, etc to guarantee QoS requirements. (Kanellopoulos, 2019).

In terms of the Open Systems Interconnection (OSI) reference model, the scheduler is placed to work in between the routing algorithm and upper the medium access control MAC sublayer as indicated in Figure 4.1

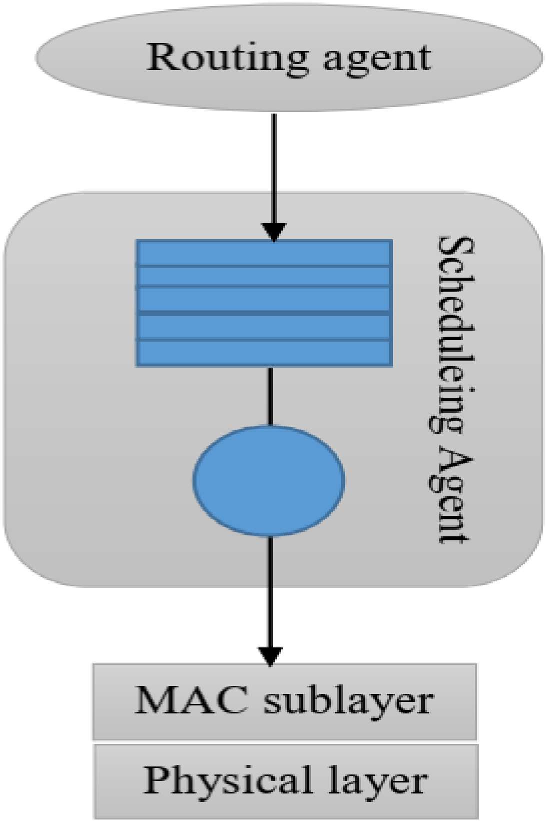


Figure 4.1: The position of the scheduling agent among the routing algorithm and the MAC sublayer.

In the literature of optimizing routing algorithms, the meta-heuristic optimization methods were only considered to provide the optimal path. Unfortunately, these meta-heuristic optimized routing protocols do not consider the packet scheduling method which are can participate effectively to ensure QoS provision. In this research work, non-real-time packet scheduling was considered through applying a hybrid optimization mechanism based on minimum execution time (MET) as packet scheduling method and Moth Flame Optimization (MFO) scheme to provide an optimal route. A further detailed explanation about the minimum execution time (MET) scheduling algorithm and moth flame optimization (MFO) scheme will be introduced later in section 4.3.2 and 4.3.3.

4.2 Naturally Inspired Algorithms With The Routing Methods

Before nearly half a century ago, researchers and experts in engineering and computer science began to implement algorithms derived from the natural behavior of some creatures in nature, Theses developed algorithms called natural bio-inspired algorithms and they mainly developed to solve problems which difficult to be solved using classical analysis approaches (Harrag, 2018; Holland, 1975). The features of biological systems which including robustness, adaptively, and sophistication have highly motivated to replicate the natural evolving mechanism in an attempt to develop systems based on software and hardware components with competitive features to those original biological systems (Harrag, 2018).

The term Meta-heuristic can be divided into two words Meta and heuristic higher words. Meta is a Greek word and it refers to the higher or upper level whereas heuristic represents a solution technique based on trial and error method to generate appropriate solutions for a complicated problem with reasonable practically time (Bhattacharyya, 2018; Yang, 2010). The problem complexity in interesting research fields which making the impossibility to discover each possible solution or combining, the goal is to obtain good and applicable solutions in a reasonable timeframe. Examples of natural meta-heuristic algorithms include GA, ACO, PSO, ABC, MFO. In this section, the theoretical principles, basics, and related aspects to metaheuristic algorithms will be introduced.

1. *Optimization problem definition*

This aspect can be defined as a problem that needs to decide on selecting a solution between several solutions in a computing science optimization problem under some desired objectives. The chosen solution is known as an optimal solution .any optimization problem is classified as NP-problem if it can not be solved using a polynomial algorithm. In terms of our research area which belongs to MANETs, the routing issue is described as an optimization issue in which the efficient route is selected in between several possible routes leading to better performance parameters (Bitam and Mellouk, 2014).

2. ***Fitness function***

Fitness function which is also known as the objective function. It is an official function that comes as a part of the optimization problem to be used for solution evaluation in the solution space, fitness function provides extreme maximum or minimum solution showed up a quantitative value based upon one or more objectives (Bitam and Mellouk, 2014). Furthermore, in the optimization processing, the fitness function as an optimization mechanism will consider some factors called fitness factor based on the purpose of the research, in the MANETs environment, the fitness parameters are often included end delay, bandwidth, distance, the energy level of nodes, and energy consumption (Taha et al. 2017). for illustrative purposes of the fitness function in MANET, let consider the following simple example of minimization fitness function:

$$Minimize\ f\ P(S,D) = w1 * f_1 + w2 * f_2 \qquad (4.1)$$

Where

- f is a fitness function aiming to minimize two considered fitness factors by comparing different solutions (possible paths) and each path is represented as $P(S,D)$.
- f_1 and f_2 represent the two considered fitness factors in the optimization process (bi-objective optimization problem), which are affected between the sender and the target nodes. They can be a delay, bandwidth, energy level, distance or any other factor based on the purpose of the research
- $w1$ and $w2$ are weights associated with these factors, and the summation of these factors will equal 1.

3. ***Solution search space***

Solution search space refers to the search area which includes all feasible and possible solutions to a certain optimization problem .these feasible solutions are gathering in a discontinuous or continuous set (Bitam and Mellouk, 2014). Solution search space is described as in Figure 4.2 which represents all feasible evaluated solutions for a certain optimization problem. The best-obtained solution over the whole search space is named as the global optima. Whereas, the best solution in a certain search region is called local optima.

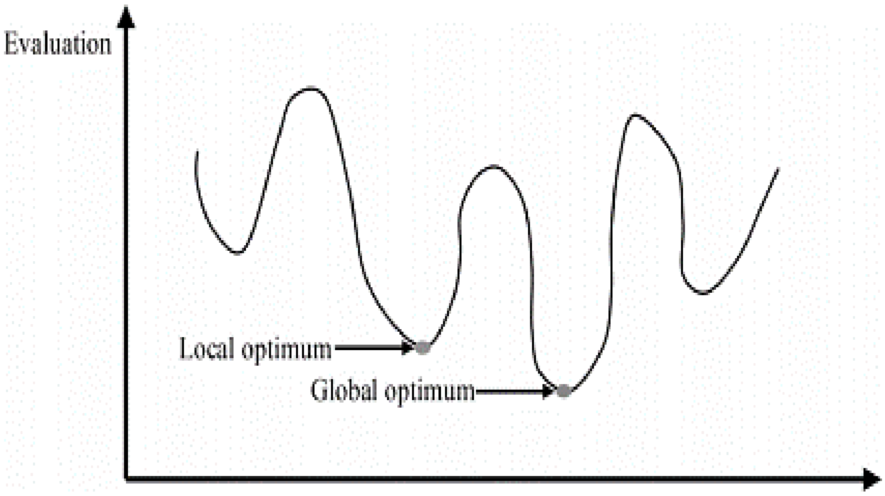


Figure 4.2: Solution search space in a certain optimization problem (Bitam and Mellouk,2014)

4. *Population*

It represents a group of feasible solutions known as individuals selected from the solution space, the population is depicted by the size which shows the number of solutions belongs to the population (Bitam and Mellouk, 2014). As an example below, it shows a population characterized with size = 5.

I_1	I_2	I_3	I_4	I_5

Here, I_i is an individual (solution). And the solution, for example, represents the route between source and destination.

5. *Initialization*

The first procedure in the optimization mechanism is an initialization, the aim of this procedure is to initially create the population by selecting a set of solutions from solution search space (Bitam and Mellouk, 2014). There are two approaches to initialize the population, the first one is the random method, which is based on selecting the first population individuals randomly from solution search space (Bitam and Mellouk, 2014). The second method is named a greedy method. It is unlike a random method, the greedy method uses the logical idea to initialize the population, For an instant, population members can be chosen one by one (sequentially) based on the distance factor which can be considered in the problem objectives (Bitam and Mellouk, 2014).

6. ***Terminating criteria***

Terminating criteria which also known as stopping criterion is an assigned value to control operation time of certain optimization approaches (Bitam and Mellouk, 2014). This terminating criterion can be represented in the form of fixed iterations number which is called, in this case, static stopping criterion (Bitam and Mellouk, 2014). On the other hand, dynamic terminating criteria can also be utilized to stop the optimization approach, in which the iterations of the optimization method are performed and ended only when the objective function is not improved after a specific time number (Bitam and Mellouk, 2014).

4.3 Optimized Routing Technique Used For Optimal Route Selection

In this research, we concentrated on implementing a novel and efficient routing approach based on using a hybrid optimization mechanism. The introduced approach utilizing DSR protocol and applying hybrid optimization based on MET scheduling and MFO algorithms as a unique hybridization technique.

1. ***Dynamic source routing protocol (DSR)***

This is a reactive approach used in MANETs (Tareq, et al. 2017; Rao, et al. 2012; Zhang, et al. 2018). DSR differs from other routing approaches as it follows the source routing concept, which indicates that the node has the data to be transmitted will be responsible to discover and find a multi-hop path to reach the target node (Zhang, et al. 2018; Chatterjee and Das, 2015; Varshney, et al. 2014). If any node owns data packets for transmission, it directly begins to searching in the cache based on the routing table to decide whether a path to the target node exists or not. If the source discovers multiple paths, the minimum hop path will be chosen and embedded as a header in the transferred data packet (Zhang, et al. 2018; Chatterjee and Das, 2015), if not, two basic stages including route discovery and maintenance will be applied (Tareq, et al. 2017; Zhang, et al. 2018; Onyemelukwe, 2013; Johnson, et al.2007).

- *Route discovery phase*

In this stage, a route request (RREQ) messages which consist of unique ID, address of the source, and the address of destination will be utilized in this phase (Chatterjee and Das, 2015). This RREQ is flooding by the sender node toward all other nodes in the ad hoc network. Each intermediate node receiving the request will check to look whether it knows the target node, if not, the intermediate hub (node) adds its address and forwarding the RREQ until it reaches the destination node. At that time, the destination node sends a route replay (RREP) packet reversely to the source. The send back packet includes route details gathered from the RREQ, which saved in the source's cache to be used for communication purpose (Zhang, et al. 2018; Chatterjee and Das, 2015). Figure 4.3 explains the route discovery stage, in which N_1 is the sender node and N_7 represents the target node. To obtain the route, two RREQs packets assigned unique ids id=3 and id=1 respectively will broadcast and two paths will be founded, which include path 1 [N_1, N_2, N_3, N_7] and path 2 [N_1, N_4, N_5, N_6, N_7]. , path 1 will be chosen to transfer data because of minimum hop results

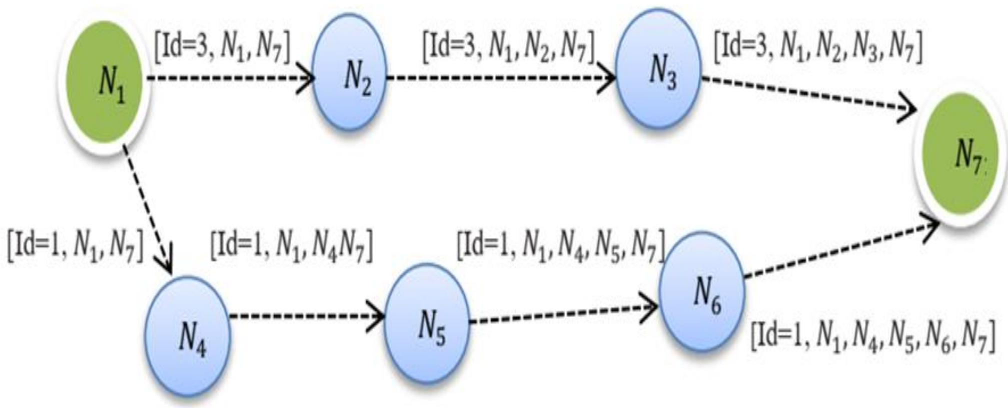


Figure 4.3: Route discovery phase.

- *Route maintenance phase*

This aim of this phase to establish alternative paths in case of current path failures to carry on the data packets transmission. In this phase, the source node gets a route error (RERR) packet so that it removes the expired path from the cache to begin a new searching process for an alternative route (Tareq, et al. 2017). Figure 4.4 shows the route maintenance stage.

When the link connected node N_3 and target node N_7 is broken, the N_3 as the intermediate node sends a RERR packet through N_2 toward the source which is N_1 .

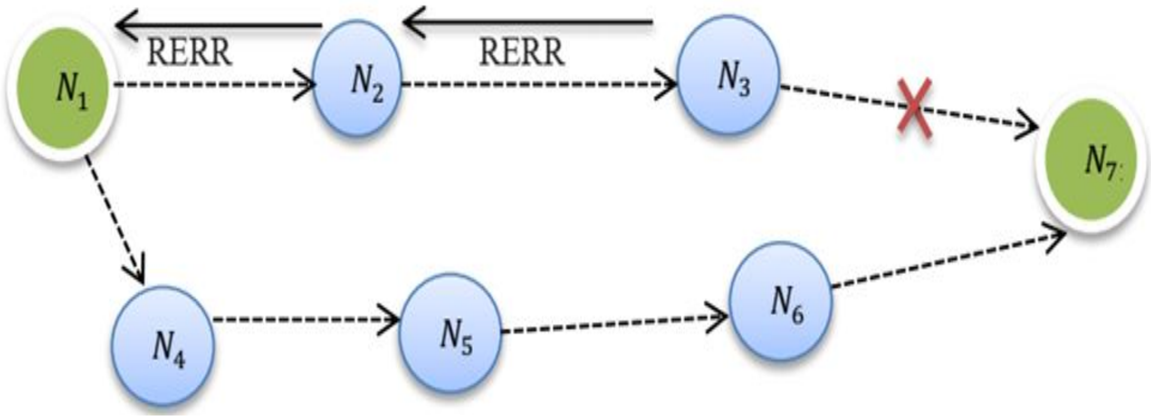


Figure 4.4: Route maintenance phase

2. ***Minimum execution time (MET) scheduling algorithm***

In general, scheduling mechanism in MANETs can be efficiently applied to improve the routing method performance which will be reflected on the whole performance on the network, The scheduling mechanism in MANETs can be described as an algorithm which copes with allocating the packets (requests or data) to the mobile nodes of MANET (Kim and Kim, 2004). Using an efficient scheduling algorithm in MANETs environment resulted in increasing the effectiveness of utilizing offered resources and shorten the delay and energy consumption for mobile nodes. MET is one of the scheduling methods, which assigned the requests or tasks to the machine (node) according to the better-predicted completion time interval for the processing without considering the accessibility of the resources (Hemamalini and Srinath 2016; Madni, et al. 2017). The basic objective of applying the MET process is to proceed with the data packets on certain nodes through lower execution time. This leads to a high packet delivery rate and throughput and decreases the packet delay time transfer. The essential procedure of the applied MET algorithm in the DSR approach can be presented in the following pseudo-code below.

MET in DSR Pseudo-code

for i =1: N_r ;N_r is the number of data packets need scheduleding.
for j =1: N_m ; N_m refers to the total number of nodes.
$E_{ij} = (T_{ij} \times P_{ij}) / RT_{ij}$; E_{ij} is the time estimated to execute the request.
; T_{ij} is the time required for each request to complete the execution.
; P_{ij} is the packet which is presently executing.
; RT_{ij} is the arriving time of the request or packet
$R_{ij} = (AT_{ij} \times P_{ij}) / RT_{ij}$; R_{ij} is the time which the packet ready for execution
; AT_{ij} is the available time of the packet or request.
$C_{ij} = E_{ij} + R_{ij}$; C_{ij} is the completion time
end for
end for
do until all unscheduled packets or requests are finished
for each unscheduled packets or requests
find the best completion time E_{ct} of packet or request and the machine that receive it
end for
find the packet or request t_p with the earliest completion time
Assign the packet or request t_p to the node that shows the best completing time
Remove allocated packet or request t_p from unscheduled pull
Update the ready time of the node which indicates the best completion time
end do

3. ***Moth flame optimization (MFO) method***

MFO is a recent metaheuristic optimization technique that was introduced by Seyedali Mirjalili in 2015(Mirjalili, 2015). Its developing idea coming from a used mechanism by moths called navigation mechanism, which is also called transverse orientation. This mechanism is relying on the principle of moths hovering in straight direction by maintaining an immutable angle concerning the far-away moon as an efficient strategy of moving in straightway in long-distance cases as shown in Figure 4.5 (Mirjalili, 2015; Shehab, et al. 2019; Shah, et al. 2018). Despite the transverse orientation mechanism is an efficient method for insuring the hovering in a straight direction, it is noticed as shown in Figure 4.6 that hovering pattern alert in case of the human-made light environment as the distance not far as in the moonlight situation (Mirjalili, 2015; Shehab, et al. 2019). The mathematical description of such a process is known as moth flame optimizing

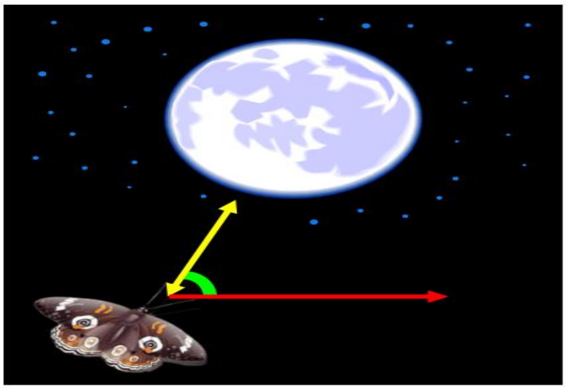


Figure 4.5: Transverse orientation [9]

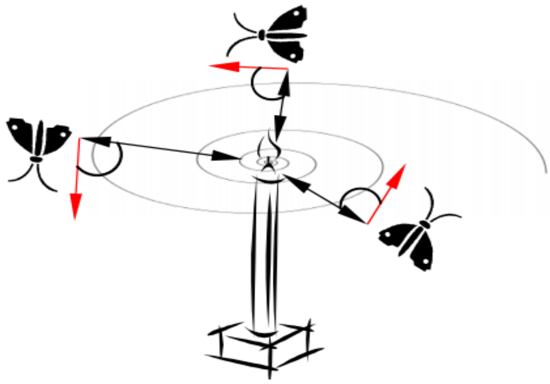


Figure 4.6: Flying pattern around artificial light [9]

MFO is utilized in this dissertation as in the following steps:

Firstly, initialize moths in random positions, which considered possible solutions in the search area. This initialization of moths is represented as follow:

$$M = \begin{bmatrix} M_{1,1} & M_{1,2} & \dots & \dots & M_{1,d} \\ M_{2,1} & M_{2,2} & \dots & \dots & M_{2,d} \\ \vdots & \vdots & \vdots & \vdots & \vdots \\ \vdots & \vdots & \vdots & \vdots & \vdots \\ M_{N,1} & M_{N,2} & \dots & \dots & M_{N,d} \end{bmatrix} \quad (4.2)$$

Where N is the total number of moths and d is the number of variables which are also known search space dimension. The fitness value for an individual moth is organized as follows:

$$OM = \begin{bmatrix} OM_1 \\ OM_2 \\ \vdots \\ \vdots \\ OM_N \end{bmatrix} \quad (4.3)$$

Another important parameter in the MFO algorithm which is flames.it can be described in a similar matrix as used for moths in the following manner

$$F = \begin{bmatrix} f_{1,1} & f_{1,2} & \dots & \dots & f_{1,d} \\ f_{2,1} & f_{2,2} & \dots & \dots & f_{2,d} \\ \vdots & \vdots & \vdots & \vdots & \vdots \\ \vdots & \vdots & \vdots & \vdots & \vdots \\ f_{N,1} & f_{N,2} & \dots & \dots & f_{N,d} \end{bmatrix} \quad (4.4)$$

Where N represents the total number of moths whereas. Similarly, the fitness value for an individual flame can be represented in the following array:

$$OF = \begin{bmatrix} OF_1 \\ OF_2 \\ \vdots \\ \vdots \\ OF_N \end{bmatrix} \quad (4.5)$$

Another point should be stated which is both flames and moths are solutions; but the operable difference among them is moths refers to search operatives to discover the solution space, on the other hand, flames represent the best solution achieved until the present. Alternately, flames can be viewed as a flag or sign attended by the moths at the searching process time.
In MFO, there are three functions used to estimate the global optima in the optimization problem. These utilized functions are:

$$MFO = (I, P, T) \quad (4.6)$$

Here, I function generates a population of moths randomly with their representational fitness values. This I formed as follows

$$(I: \emptyset \rightarrow \{M, OM\}) \quad (4.7)$$

The second basic function is P, which indicates the movement of moth in the solution zone. This function inputted with M and returned updated copying as output

$$P: M \rightarrow M \quad (4.8)$$

The third function is stoping criteria function. It is a T function that represents the search completion process. It resulted in false value when the termination does not meet and true value when is meet

$$T: M \rightarrow \{true, false\} \quad (4.9)$$

As said earlier, Moths are using a transverse orientation technique, which can be formulated in mathematic form using the function I. This function is using the random distribution tool to create initial solutions and calculating their corresponding values as the following equation:

$$M(i, j) = \left(ub(i) - lb(j)\right) * rand\ ( ) + lb(i) \tag{4.10}$$

Here ub(i) refers to the upper bound and variable lb(i) defines the lower bound.

The new position for the moth is updated to the flame according to the next formula:

$$M_i = S\left(M_i, F_j\right) \tag{4.11}$$

Here, S describes the logarithmical spiral function, M_i refers to the i-th moth and $F_j$defines the j-th flame. The S spiral function is applied to obtain the updated positions of the moths regarding the flame. Three conditions must be satisfied in logarithmical spiral function which listed below :

- The spiral range variations should not exceed the defined search space.
- The moth position must define the starting point of the spiral.
- The spiral endpoint should be represented by the position of the flame.

In MFO, the spiral function which used to update the position of moth can be represented mathematically as follow:

$$S\left(M_i, F_j\right) = D_i . e^{bt} . \cos(2\pi t) + F_j \tag{4.12}$$

Where D_i defines the distance between the M_i and the F_j, b represents a constant number which defines the shape of spiral function, and t is the size of step for the moth in the next position toward the flame direction. It is a random number with a value between -1 and 1. D_i is determined according to the following formula:

$$D_i = \left|F_j - M_i\right| \tag{4.13}$$

There is another problem which is decay in the exploitation mechanism to provide the best solution in terms of updating the position of the moth for n different locations in search space. Thereby, an adaptive strategy is used to work with the flame number. This strategy shows how the number of flames during the iterations will adaptively decrease. The following formula is applied in this aspect:

$$\text{Flame No.} = \text{round}\left(N - l * \frac{N-1}{T}\right) \tag{4.14}$$

Where l is the current iteration, T represents the highest iterations number and N defines the number of flames.

4. *Proposed MET-MFODSR protocol*

This research proposes a new enhanced version f the traditional DSR scheme based on utilizing MET scheduling and population-based meta-heuristic MFO (Hybridization) to enhance the routing process in MANET by providing an optimal path with lower energy consumption and less overhead ratio, and this will prolong the lifetime of the network and reduces route breakage problem. The main procedures of introduced MET-MFODSR algorithm are described below:

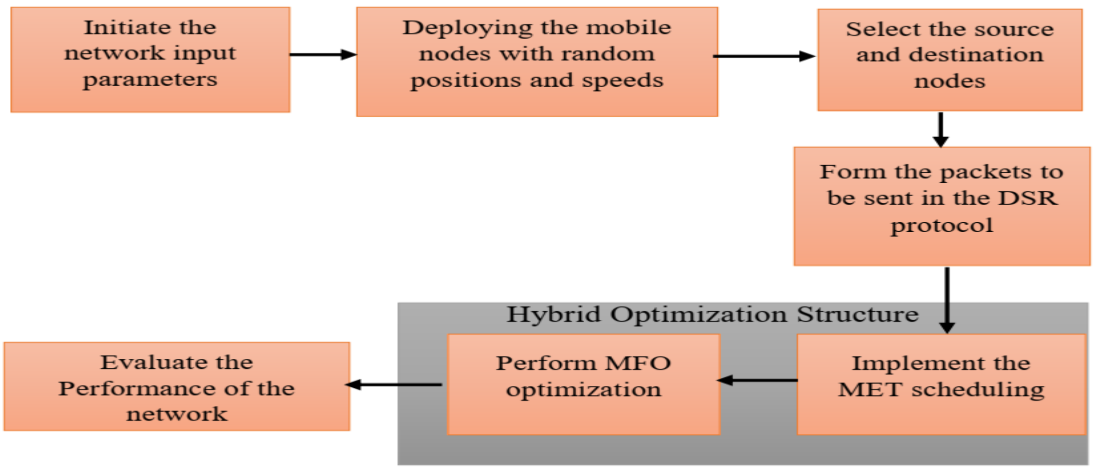


Figure 4.7: Flow diagram of the proposed MET-MFODSR algorithm.

This Figure provides the flow diagram of the main procedures of the proposed algorithm that concentrated on applying a unique hybrid optimization strategy to enhance the performance of the classical DSR approach and provide optimal path under the MANET environment. The procedures are described in details as follows:

- It starts with defining the MANET network input parameters such as length of network and width, number of nodes, initial energy, transmission range, transmission power, and so on.

- This MANET network consists of mobile nodes as the main components which in nature are moving randomly with random velocity in the defined network range .this resulted in a dynamic topology environment.
- Selecting among deployed nodes the source and destination. those nodes used for this purpose selected to have a higher energy level than the average energy level to guarantee the packet transmission for route discovery and maintenance procedures.
- Create the packets which be used in the DSR method for route initialization by forwarding route request packets and evaluate the distance from the sender to the target node. the distance is determined using the following formula

$$Dis = \sqrt{(x_d - x_s)^2 + (y_d - y_s)^2} \quad (4.15)$$

Where Dis is the calculated distance, x_d is the destination x-coordinate, x_s is the source x-coordinate, y_d is the y-coordinate for destination node and y_s is the y-coordinate for the source node. if the sender and the target located within the communication range of each other, then they can communicate directly. Otherwise, the distance between the intermediate nodes calculated based on the same formula, and if this resulted distance is located within the defined communication range, the node id, distance, X, and Y locations of the intermediate nodes and the speed of neighbor nodes for each node will be stored.

- Determine the path to the destination with the minimum hop distance and another alternative path.
- The next applied step is the hybrid optimization process to increase the throughput, minimize the time delay, reduce routing overhead, and energy consumption which leads to prolonging network lifetime and reducing link disconnection issue. The hybrid optimization structure is based on MET scheduling and the MFO algorithm.
- The MET scheduling as described in(MET in DSR Pseudo-code) used to deliver and execute more packets in the neighboring nodes which resulted in successfully broadcasting more packets in less computing time thereby throughput will increase.
- Apply the MFO method by defining the lower and upper bounds of the solution space and create the population-based by considering the nodes in the network as the moths. These nodes (moths) are considered potential solutions and stored in a matrix as presented in the equation (4.1), and their positions are considered as search solution space. This search space is created using equation (4.10) based on some defined

parameters which include the dimension of search (d), the lower bound lb(i) and the upper bound ub(i).

- The used fitness function to evaluate the fitness value is defined as follows :

$$\text{Min. Fi}=(E_x \times D_x)/ N_P \quad (4.16)$$

Where E_x represents the consumed energy by the node (moth) in a particular position, D_x refers to the distance under the cover of the node (moth) and) and N_P is the number of nodes (moths). after the fitness value evaluation, the location of each month (node) will be updated using the logarithmic spiral formula as given in the equation (4.12).

- The performance of the proposed MET-MFODSR will be assessed using five performance parameters These five metrics are including the A E-E D, PDR, average throughput, average energy consumption, and routing overhead ratio.

5. *Pseudo-code of MET-MFODSR protocol*

The pseudo-code implementation steps of the proposed MET-MFODSR protocol are introduced in the following procedures:

Input: Network area, Number of nodes, the initial energy of nodes, Transmission Power, Transmission Range, Packet size, nodal speed, Total simulation time, Lower bound (lb), Upper bound (up), Dimension, Logarithmic spiral shape constant (b).

1. Initialize the mobile nodes ($mn_i = mn_1, mn_2, \ldots, mn_N$) where N=50 nodes.
2. Deploy random locations of the nodes in the network range.
3. Evaluate Avg_energy=mean(node_energy).
4. **for** i=1: N

    if (node_energy (i) > Avg_energy)

    store id of the node

    End if

   End for

5. Chose the source and the destination nodes from those having higher energy than the average energy and identify their Ids.
6. Generate the packets or requests of the DSR algorithm.

7. Broadcasting RREQ packets to start routing initialization.
8. Calculate the Dis $=\sqrt{(x_d - x_s)^2 + (y_d - y_s)^2}$; where Dis is the distance from the sender to the target.

9. **If** (Dis < = T_R) ; T_R = Transmission Range
   Source and destination communicate immediately.
   Else
   Find the distance separate the intermediate hub nodes.
   If (Dis > 0 && Dis < T_R)
   Save X_L , Y_L , id, speed and Dis of ; X_L , Y_L are X and Y locations nodes
   End if
   End if
10. Determine the minimum hop path and an alternative path to the destination.
11. Apply the MET scheduling technique
    for k =1: M
    for l =1: N
    $E_{kl}= (T_{kl} \times P_{kl})/ RT_{kl}$
    $R_{kl} = (AT_{kl} \times P_{kl})/ RT_{kl}$
    $C_{kl} = E_{kl} + R_{kl}$
    End for
    End for

Where M is tasks need scheduling, N is the number of nodes ; E_{kl} is the estimated time for packet execution; T_{kl} is the time required per request to complete the execution at the receiver node; P_{kl} the presently executed packet; RT_{kl} is the packet or request arrival time; R_{kl} is ready time of the request or packet to be executed; AT_{kl} the availability time of the task to be executed; C_{kl} is the completion time.

12. Sort the minimum completion time in ascending order as follows

    min_comp_time = sort(min_comp_time,'ascend')

13. Stop MET when all unscheduled packets or requiests are finished.

14. Apply the MFO method by starting creation of the search space

```
for i=1: n                                  ; n = search agents
   for j=1: d                               ; d = the dimension
   M(i,j)=(ub(i)-lb(j))*rand ( )+lb(i)      ; ub is upper bound and lb is lower bound
   End for
End for
```

15. **WHILE** (iteration < =max. iteration)

16. Evaluate the fitness value for each node (moth) using equation (4.16).

17. min_fitness_value = sort(min_fitness_value,'ascend') ; sort minimum fitness value ; in ascending order

18. Update the locations of each node (moth) using equation (4.12).

19. Iteration= Iteration+1

20. **WHILE END**

21. Obtain the coordinates of best forwarding intermediate nodes with the lowest fitness value to transfer the data packets through it.

Output: Optimal packet forwarding route.

4.4 Performance metrics

In this thesis, there are five performance parameters are used to assist the performance of the introduced MET-MFODSR routing approach. These five metrics are described below including A E-E D, PDR, average throughput, average energy consumption, and routing overhead ratio.

- A E-E D: This term represents the needed average time to successfully forward the data bundle between the sender and target (Tareq, et al. 2017; Hu, et al. 2011; Gujral, et al. 2012). The delay factor consists of many delay components which are buffering delay as a result of the route searching process, queuing delay results of the router interface line, MAC time delays results from retransmission mechanism, propagation time delay, and transmission time delay. If this metric shows a less time delay during experimental simulation then a better performance of the routing algorithm is achieved. This parameter can be obtained according to the following mathematical formula (Taha et al. 2017; Tareq, et al. 2017):

$$\mathrm{A\,E-E\,D} = \frac{\sum_{\mathrm{i=1}}^{\mathrm{i=n}}(\mathrm{Ri} - \mathrm{Si})}{\mathrm{n}} \qquad (4.17)$$

Where Ri is the time of the received packet, Si is to the time of the transmitted packet and n is the total number of data packets.

- PDR: it describes the ratio between the data rate packets which reaches its destination successfully and the total data packets generated at the source (Taha et al. 2017; Tareq, et al. 2017; Perkins, 2001; Ali et al. 2014). when this performance parameter shows a higher ratio, it will indicate that the routing algorithm has better performance and reliability. The mathematical formula used for this parameter is following (Tareq, et al. 2017; Ali et al. 2014; Clausen and Jacquet, 2003):

$$\mathrm{PDR} = \frac{\sum \text{received data packet}}{\sum \text{transmitted data packets)}} \times 100 \qquad (4.18)$$

- Average throughput: it is defined as the number of packets that reached successfully to the destination within the simulation time and it is measured in kilobits per second (kbps) unit. (Taha et al. 2017; Tareq, et al. 2017; Hu, et al. 2011). This parameter indicts how the routing algorithm is efficient in data packet receiving at the sink. As it is a higher value, it means a more effective routing approach. The descriptive equation of this index is given as follow (Johnson et al.2001; Zhang et al.2018):

$$\text{Average throughput} = \frac{\sum \text{The number of received bytes}}{\text{simulation time}} * \frac{8}{1000}\ \text{kbps} \quad (4.19)$$

- Average energy consumption: it is the ratio between the total energy consumed by the mobile node and the initial energy level, the initial level of energy and remaining energy can be obtained at the end of the simulation process, the desired and efficient routing algorithms should indicate less energy depletion which reflects the better performance.this index is calculated using the following formulation (Taha et al. 2017; Tareq, et al. 2017):

$$\text{Average energy consumption} = \frac{\sum \text{energy consumed}}{\sum \text{initial amount of energy}} \times 100 \qquad (4.20)$$

- Routing overhead ratio: It refers to the ratio between the number of transferred routing packets to the total number of data packets plus routing packets (Taha et al. 2017; Tareq, et al. 2017). This concept provides an idea about the efficient bandwidth utilization to deliver information packets. the following formula is used to calculate the routing overhead ratio (Taha et al. 2017; Tareq, et al. 2017):

$$\text{Routing Overhead \%} = \frac{routing\ packets}{routing\ packets + data\ packets} \times 100 \qquad (4.21)$$

CHAPTER 5
SIMULATION AND RESULTS DISCUSSION

5.1 Experiments Setup And Input Parameters

The experimental simulation and evaluation of the proposed routing MET-MFODSR method are performed using the MATLAB platform version on the operating system Windows 10 installed on Intel Celeron 1.60 GHz processor and 4 GB RAM. This experimental simulation accomplished on 1670 m × 970 m network simulation area with a total of 50 mobile wireless nodes distributed randomly over the network area, for each mobile node, the transmission range is 250 m, whereas, the level of the initial energy is fixed to 100 joules, while, the total simulation time is set to 50s. The performance evaluation of the introduced MET-MFODSR method will be evaluated and compared with the existed BEE-DSR protocol (Tareq, et al. 2017) and the BeeIP protocol (Giagkos and Wilson, 2014). The nodes' speed has altered between 5 and 20 m/s. Table 5.1 highlighted the main setting of the input simulation parameters.

Figure 5.1 illustrates the topology structure of the network which consists of 50 nodes in a magenta color are initialized in random positions over the network area.

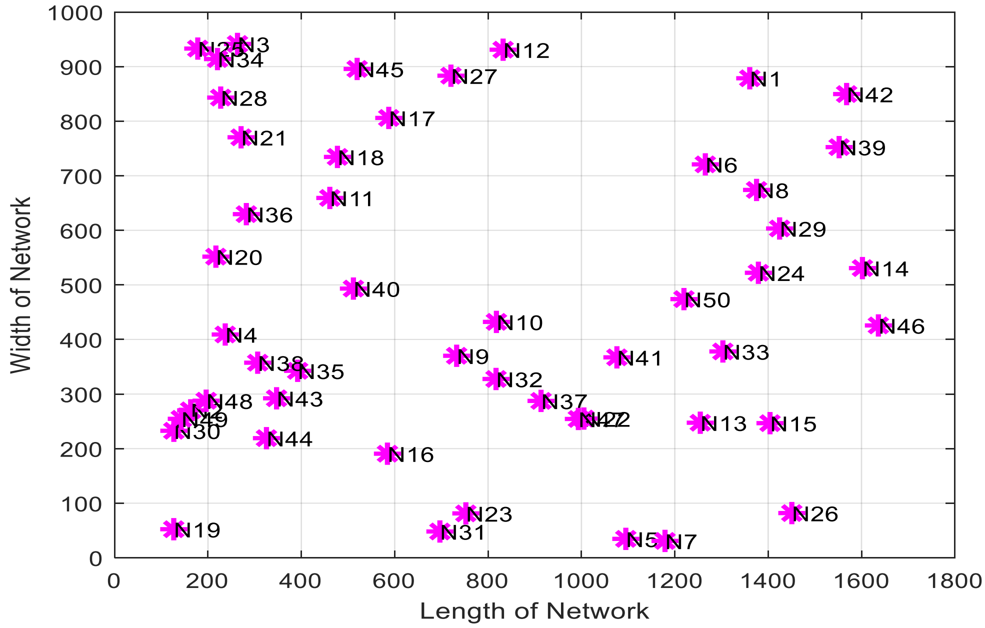


Figure 5.1: Network topology

Table 5.1: Parameters of simulation settings

Parameter	Value	Unit
Network area	1670× 970	m^2
Number of nodes	50	Node
The initial energy of nodes	100	Joules
Transmission Power	1.35	mw
Transmission Range	250	m
Packet size	256	Bytes
Nodal speed	5-20	m/s
Total simulation time	50	Sec
Lower bound lb	-100	-
Upper bound ub	100	-
Dimension	100	-
Logarithmic spiral shape constant (b)	1	-

Figure 5.2 indicates the nodes which have a high energy level in the network and they are marked in the blue color circle. The blue color circle around the nodes refers to the nodes having high energy than the average energy of the nodes. These are evaluation is required to select the source and the destination from these circled blue color nodes and this important to grunted that the source node has sufficient energy to transfer the data packets during route discovery and maintenance mechanisms.

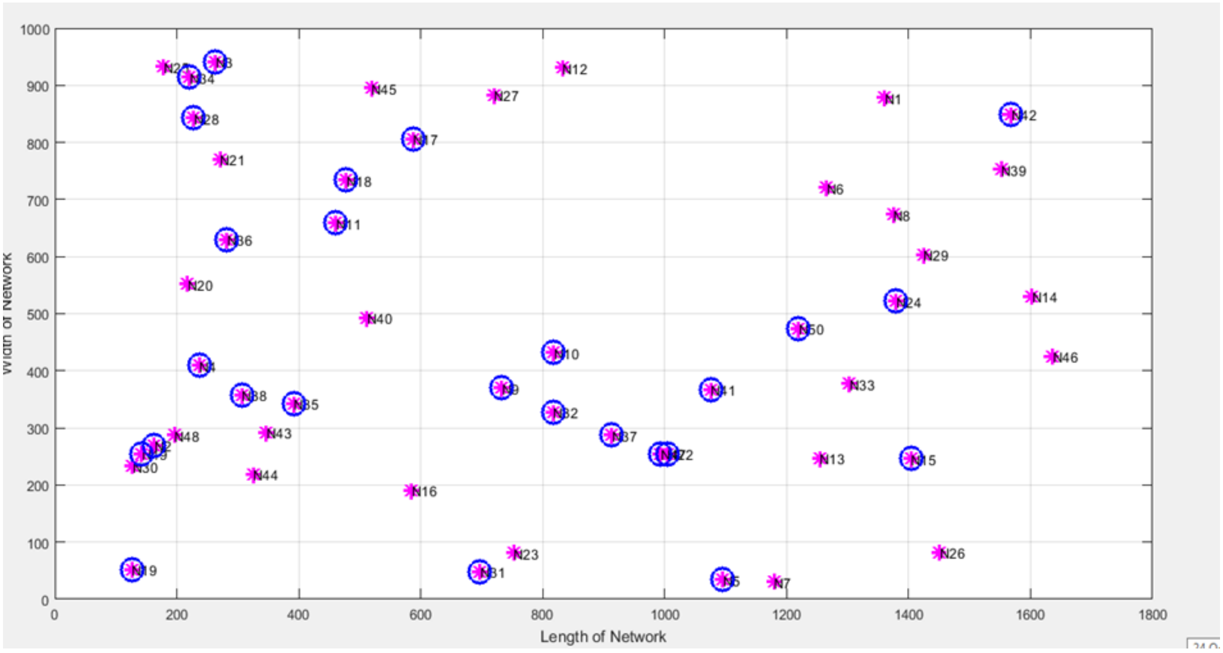


Figure 5.2: High energy nodes selection

Figure 5.3 shows the node id in the message box of each marked circle blue color in figure 5.2. These nodes are having a higher energy level than the average. This is evaluated by comparing each node's energy with the calculated average energy of the nodes that forming the network.

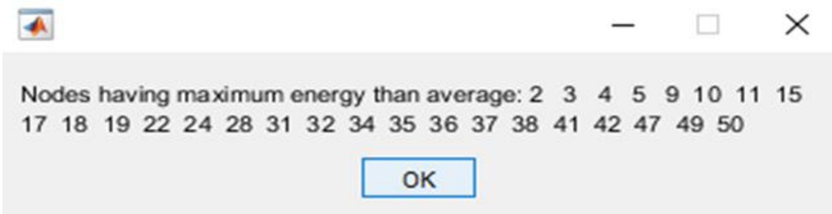


Figure 5.3: Node Ids having higher energy than average

Figure 5.4 indicates the source id and destination id in the message box. It is necessary to identify the Ids of the source and destination because the route initializing and broadcasting will be performed by source and packets transferring to the destination node, also it is needed to evaluate the path with minimum hop distance which is impossible without identifying the source and destination ids. It can be noticed that the node ids which are selected as source and destination are included in the list shown in Figure 5.2

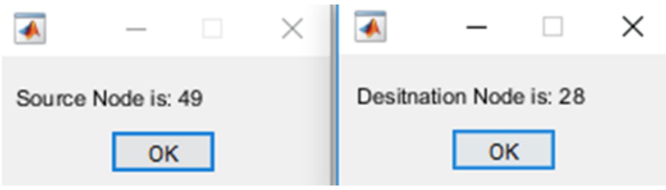


Figure 5.4: Source and destination Ids

Figure 5.5 shows the RREQ packet broadcasting process through the source node. This mechanism is considered as the route initialization phase and it is a fundamental stage in the DSR protocol, these requests send to all the nodes because the source wants to send on-demand packets to the destination.

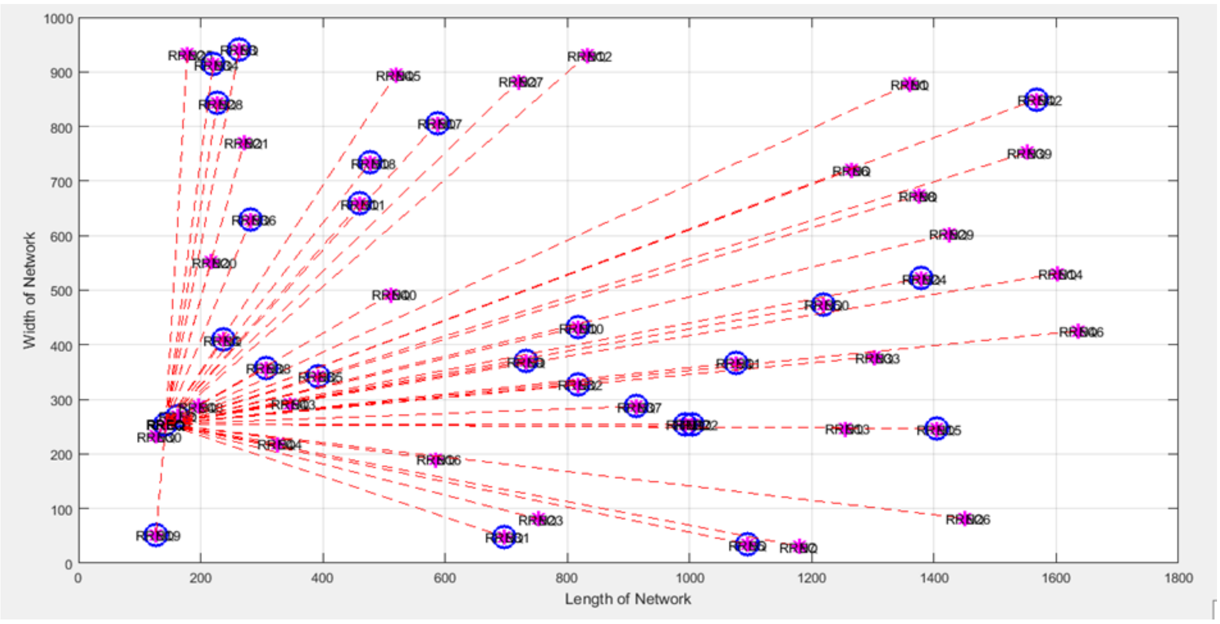


Figure 5.5: Broadcasting of the RREQ packets

Then the source will obtain the coverage nodes which show the availability of the neighbor nodes in the network to send the packets. Figure 5.6 shows the portion of the coverage nodes of some nodes by showing the nodes are coming under the transmission range of each node. The transmission range is selected as 250 m. The coverage area is evaluated to obtain the neighbor nodes of all the nodes presenting in the network. For example, it can be seen in figure 5.6 that the coverage of 1^{st} nodes including 6th & 8^{th} nodes and other nodes ids will occur if the figure scrolled in the simulation from left to right. This means nodes with id 6, 8 are located within the transmission coverage of the 1^{st} node. The neighbor nodes Ids of each node can be obtained in the same manner.

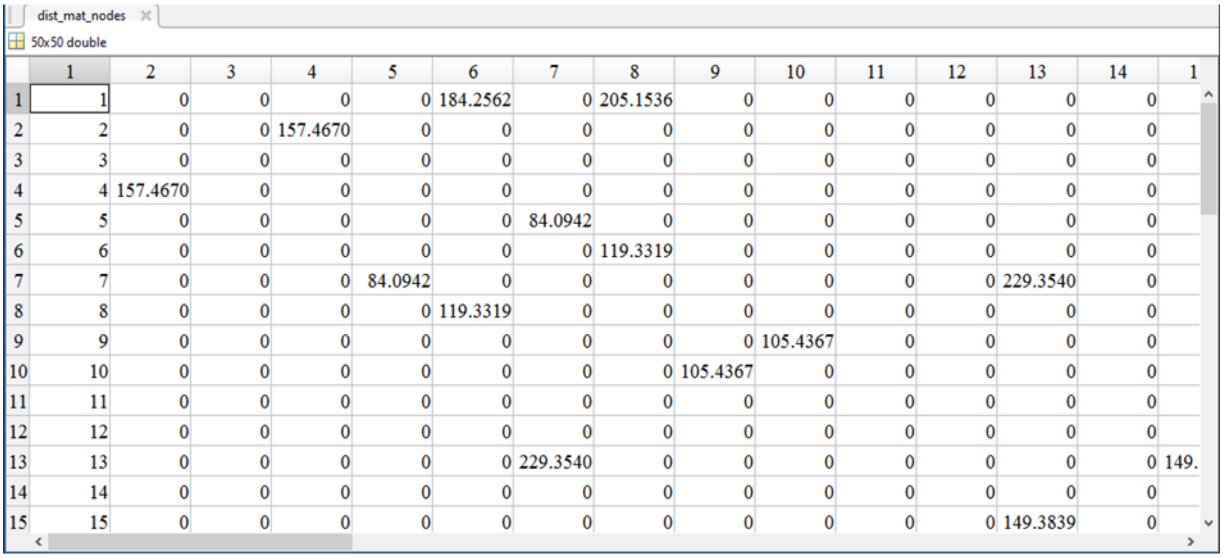
cov_area_nodes

50x50 double

	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	1	0	0	0	0	6	0	8	0	0	0	0	0	0
2	2	0	0	4	0	0	0	0	0	0	0	0	0	0
3	3	0	0	0	0	0	0	0	0	0	0	0	0	0
4	4	2	0	0	0	0	0	0	0	0	0	0	0	0
5	5	0	0	0	0	0	7	0	0	0	0	0	0	0
6	6	0	0	0	0	0	0	8	0	0	0	0	0	0
7	7	0	0	0	5	0	0	0	0	0	0	0	13	0
8	8	0	0	0	0	6	0	0	0	0	0	0	0	0
9	9	0	0	0	0	0	0	0	0	10	0	0	0	0
10	10	0	0	0	0	0	0	0	9	0	0	0	0	0
11	11	0	0	0	0	0	0	0	0	0	0	0	0	0
12	12	0	0	0	0	0	0	0	0	0	0	0	0	0
13	13	0	0	0	0	0	7	0	0	0	0	0	0	0
14	14	0	0	0	0	0	0	0	0	0	0	0	0	0
15	15	0	0	0	0	0	0	0	0	0	0	0	13	0

Figure 5.6: Coverage Nodes

Figure 5.7 shows samples of the nodes coverage distance in meters, for example, within the coverage of 1^{st} node, node 6 and 8 are coming under 1^{st} node coverage and the distance with respect of 1^{st} node is 184.25 m and 205.1536 m respectively. Besides, it can be observed these distances within the transmission range which is into the range of 0 - 250 m.



	1	2	3	4	5	6	7	8	9	10	11	12	13	14	1
1	1	0	0	0	0	184.2562	0	205.1536	0	0	0	0	0	0	
2	2	0	0	157.4670	0	0	0	0	0	0	0	0	0	0	
3	3	0	0	0	0	0	0	0	0	0	0	0	0	0	
4	4	157.4670	0	0	0	0	0	0	0	0	0	0	0	0	
5	5	0	0	0	0	0	84.0942	0	0	0	0	0	0	0	
6	6	0	0	0	0	0	0	119.3319	0	0	0	0	0	0	
7	7	0	0	0	84.0942	0	0	0	0	0	0	0	229.3540	0	
8	8	0	0	0	0	119.3319	0	0	0	0	0	0	0	0	
9	9	0	0	0	0	0	0	0	0	105.4367	0	0	0	0	
10	10	0	0	0	0	0	0	0	105.4367	0	0	0	0	0	
11	11	0	0	0	0	0	0	0	0	0	0	0	0	0	
12	12	0	0	0	0	0	0	0	0	0	0	0	0	0	
13	13	0	0	0	0	0	229.3540	0	0	0	0	0	0	0	149.
14	14	0	0	0	0	0	0	0	0	0	0	0	0	0	
15	15	0	0	0	0	0	0	0	0	0	0	0	149.3839	0	

Figure 5.7: Coverage distance matrix

Figure 5.8 indicates the message box of the minimum hope distance route in which the packets will be transferred through it. The distance is obtained based on applying the Euclidean distance formula.

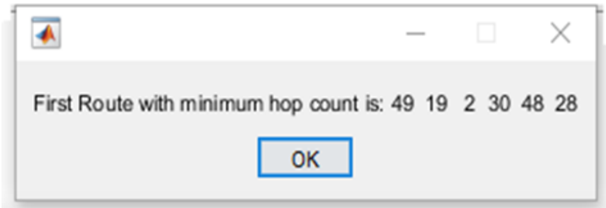


Figure 5.8: Minimum hope route

Figure 5.9 illustrates the path for packet transferring through the minimum hop distance route by utilizing the nodes which are selected as the route nodes. It can be observed that the first node is the sender while the destination is the last one.

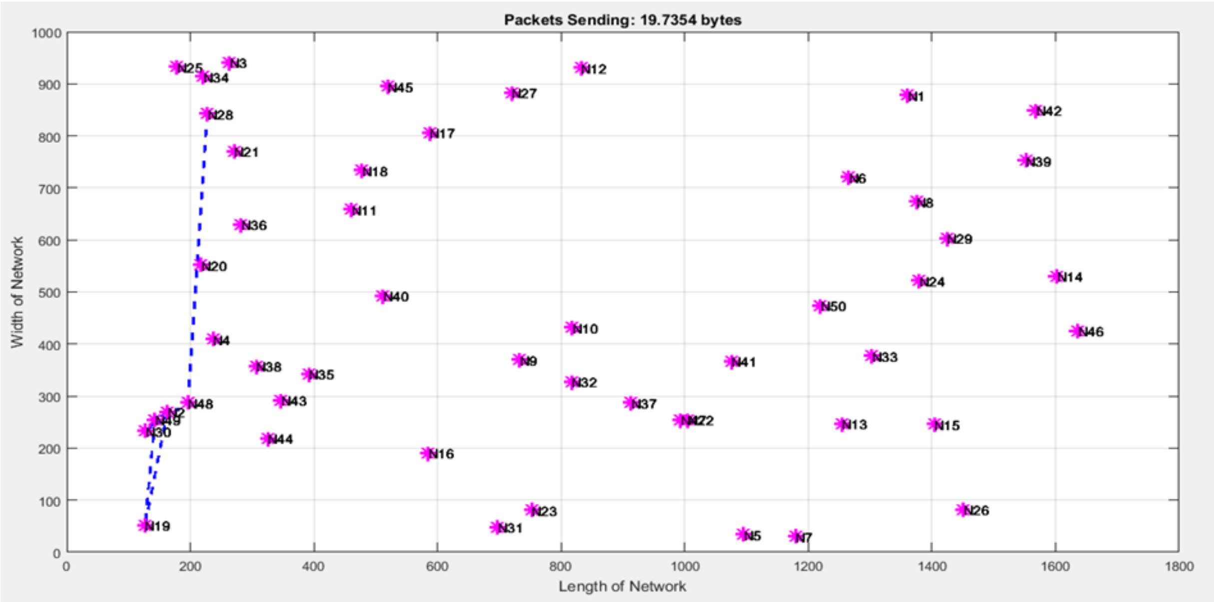


Figure 5.9: Packets transferring path

5.2 Results and Discussions

To evaluate the performance of the introduced MET-MFODSR routing method, we analyzed it and tested it compared to the BEE-DSR and BEEIP protocols. The assessment and evolution are accomplished under two scenarios:

- Scenario one: node speed variations
- Scenario two: packet size variations

5.2.1 Scenario one: Node speed variation

This scenario presents the performance parameters evolution of introduced MET-MFODSR in comparison with BEE-DSR and BEEIP. The speed was altered from 5 m/s to 20 m/s, while, number of nodes fixed to 50 nodes.

Figure 5.10 demonstrates the effect of node speed variation on the average delay for MET-MFODSR, BEEIP, and BEE-DSR algorithms. The figure indicates that the average delay increases as the speed increasing for all approaches. The reason behind that the random mobility movement of mobile nodes leads to unstable dynamic network topology.

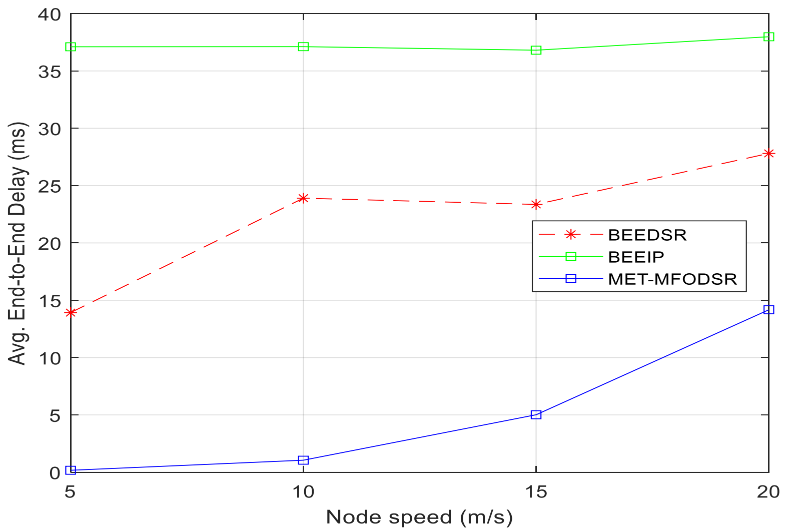


Figure 5.10: Average E-to-E D versus node speed variation for BEEDSR, BeeIP, and MET- MFODSR.

Therefore, any node needs to send data packets requires a new route discovering process to set up the path and this results in increasing the average time delay. The MET-MFODSR method provides less average delay when compared with BEEIP, and BEE-DSR approaches. For MET-MFODSR, the average delay raising from 0.1709 ms to 14.17 ms, BEE-DSR increasing from 13.92 ms to 27.81 ms and BEEIP growing from 37.11 ms to 37.98 ms. This is because the MET-MFODSR method considering the minimum hop distance to discover the path and use the MET packet scheduling which fasts the execution of the packets processing on nodes and shortened the average waiting time of packets, therefore MET-MFODSR method guaranteed lower average delay.

Figure 5.11 illustrates the impaction of node speed variation on the overhead for MET-MFODSR, BEEIP, and BEE-DSR algorithms. For all three approaches, the overhead ratio is increasing as the node speed increase, and this is resulted from increasing the broadcast of the routing-control packet including (RREQ, RREP,…) to rediscover alternative route due to dynamic environment. For MET-MFODSR approaches, the routing overhead has increased from 2.875 percent to 10.6 percent, while, in BEEIP it grows from 12 percent to 15.6 percent, and BEE-DSR was raised from 7.3 percent to 13.8 percent.

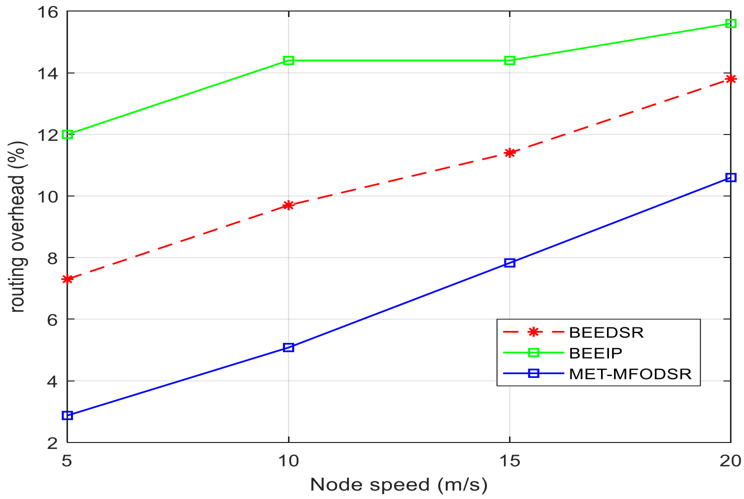


Figure 5.11: Routing overhead ratio versus node speed variation for BEEDSR, BEEIP, and MET-MFODSR

The MET-MFODSR shows a less overhead ratio in comparison with the BEE-DSR and BEEIP protocols. This is due to the advantage of using the MET packet scheduling strategy which increases the data packet delivery rate through the path compare to routing control packets. Therefore resulting in minimal routing overhead for MET-MFODSR. Further, applying the MFO algorithm to optimize the routing path by estimating node locations having minimum energy consumption .

Figure 5.12 indicates the impact of varying node speed concerning the average energy-consuming for the introduced MET-MFODSR, BEEIP, and BEEDSR schemes. It illustrates as the speed increases, the energy depletion is increasing. Because as the node moving faster, the path breakage chance will frequently occur due to unstable changeable topology, therefore, nodes need to cooperate to rediscover alternative path by exchanging rout control packets which cost the nodes energy. For MET-MFODSR, the average energy depletion raises from 0.105 percent to 0.3012 percent, the BEEIP increasing from 2.36 percent to 2.441 percent and the BEEDSR is increasing from 2.353 percent to 2.428 percent.

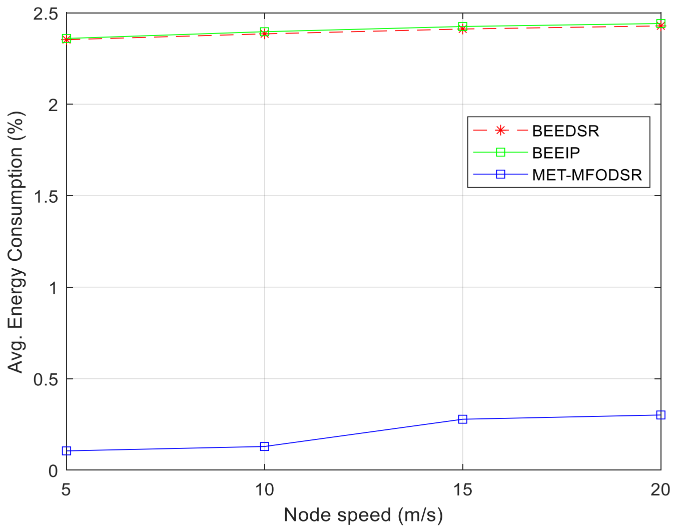


Figure 5.12: Average energy consumption versus node speed variation for BEEDSR, BEEIP, and MET-MFODSR.

The suggested MET-MFODSR exhibits lower average energy-consuming compare with BEEIP and BEEDSR which improve the network lifespan to provide further stability in the MANET. That is because the MET-MFODSR them discover the path based on the minimum distance factor. further, it utilizes the MFO technique by considering minimum energy consumption for the node to obtain the optimal path.

Figure 5.13 shows the average throughput variations concerning speed variations for MET-MFODSR, BEEIP, and BEEDSR. The figure indicates the decrement in average throughput for the node speed increment. For the MET-MFODSR scheme, The average throughput reduces from 110.2 kbps to 64.38 kbps, and in BEEIP decays from 44.19 kbps to 43.82 kbps and for BEEDSR reduces from 48.62 kbps to 46.16 kbps. Accordingly, the proposed MET-MFODSR provides higher average throughput compared to BEEIP and BEEDSR.

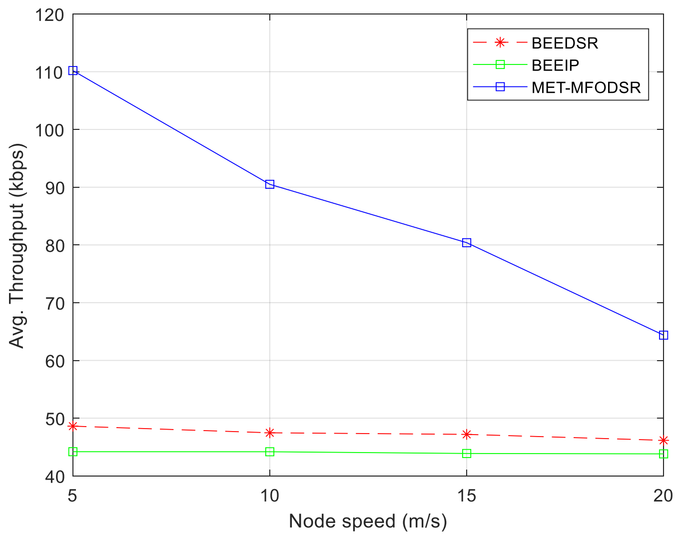


Figure 5.13: Average throughput versus node speed variation for BEEDSR, BEEIP, and MET- MFODSR.

The reason behind that the proposed MET-MFODSR applies MET as a packet scheduling approach that fasts and increases the packet processing per time unite through routing nodes resulting in a higher packet delivery ratio and consequently the throughput will be higher as PDR and throughput related to each other and have direct proportional relation. However, BEEIP and BEEDSR don’t consider a specific mechanism for packet scheduling to enhance QoS requirements.

Figure 5.14 shows how the node speed variation affects the packet delivery rate for MET-MFODSR, BEEIP, and BEEDSR. It can be observed the increment in node speed increment will cause packet delivery rate decrement due to unstable MANET topology. For the MET-MFODSR approach the packet delivery rate reduces from 99.998 percent to 99.990 percent, BEEIP decays from 99.75 percent to 99.69 percent and BEEDSR reduces from 99.78% to 99.72%. The figure indicates that the proposed MET-MFODSR scheme offers a relatively better packet delivery ratio than BEEIP and BEEDSR algorithms. This due to the proposed scheme applies MET as a packet scheduling method which enhances the execution and the delivery rate the packet, and consequently, the PDR will increment.

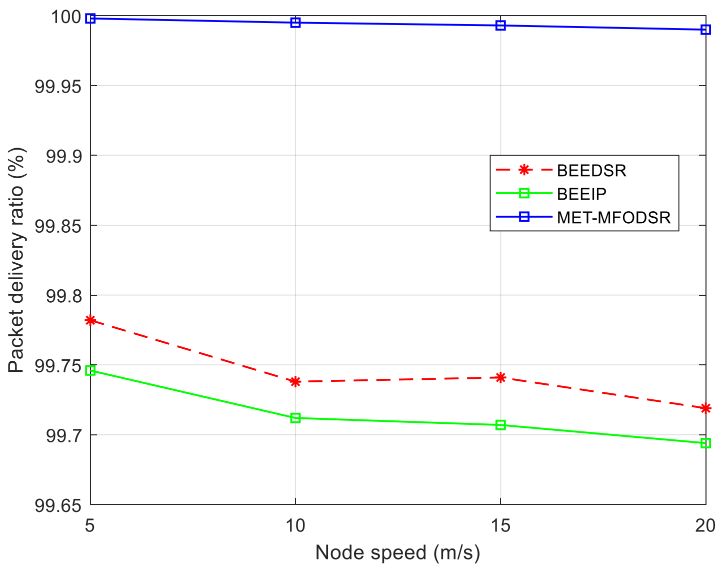


Figure 5.14: Packet delivery ratio versus node speed variation for BEEDSR, BEEIP, and MET-MFODSR.

Table 5.2 summaries the gathered simulation results details regarding the effect of node speed variations on performance matrices for MET-MFODSR, BEEDSR, and BeeIP algorithms.

Table 5.2: Node speed variations effect on the performance matrices

Node speed (m/s)	MET-MFODSR	BEEDSR	BEEIP
Average end-to-end delay (ms)			
5	0.1709	13.92	37.11
10	1.05	23.9	37.12
15	5.013	23.36	36.81
20	14.17	27.81	37.98
Routing overhead ratio (%)			
5	2.875	7.3	12
10	5.081	9.7	14.4
15	7.828	11.4	14.4
20	10.6	13.8	15.6
Average Energy Consumption (%)			
5	0.105	2.353	2.36
10	0.129	2.385	2.396
15	0.278	2.411	2.425
20	0.3012	2.428	2.441

Table 5.2: Node speed variations effect on the performance matrices (Continued)

Average throughput (kbps)			
5	110.2	48.62	44.19
10	90.5	47.47	44.18
15	80.39	47.19	43.88
20	64.38	46.16	43.82
Packet delivery ratio (%)			
5	99.998	99.78	99.75
10	99.995	99.74	99.71
15	99.993	99.74	99.71
20	99.990	99.72	99.69

5.2.2 Scenario two: Packet size variation

This scenario presents the influence of varying packet sizes on the performance matrices for MET-MFODSR, BEEIB, and BEEDSR approaches. This scenario is conducted by varying the size of the packet in the range between 128 bytes and 1024 bytes in such manner 128, 256, 512, 1024 bytes.

Figure 5.15 indicates the impact of changing packet size on the average delay for BEEDSR, BEEIP, and MET-MFODSR. With the packet size increment, the average delay increase from 27.7 ms at 128 bytes to 60.15ms at 1024 bytes for BEEDSR, and in the same manner the BEEIP raises from 31.94 ms to 70.85 ms, while in MET-MFODSR the average delay increases slightly from 3.72 ms to 6.92 ms. It can be observed that MET-MFODSR shows less average end-to-end delay than BEEDSR and BEEIP. This is because the MET-MFODSR approach uses the minimum hop distance parameter to discover the route. Further, it considers the MET method for packet scheduling which offers minimum waiting time and speeds up the packet execution process on the node which shortened the delay.

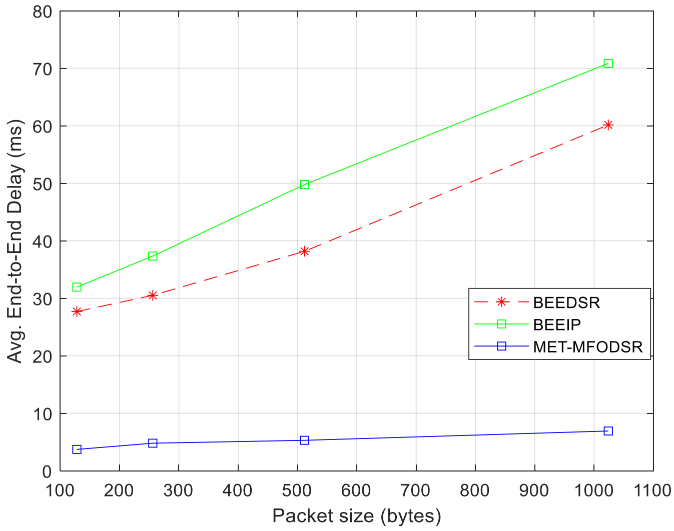


Figure 5.15: Average E-to-E D versus packet size variation for BEEDSR, BeeIP, and MET-MFODSR.

Figure 5.16 indicates the routing overhead ratio in regarding the packet size variation for the MET-MFODSR, BEEDSR, and BEEIP algorithms. As indicated in the figure, the routing overhead tends to increase slightly as the packet size increases for all three routing methods. In MET-MFODSR has increased between 0.4081 percent at 128 bytes and 1.514 at 1024 bytes percent, similarly, the BEEIP increased from 20 percent to 22.6 percent, and the BEEDSR raised from 13.9 percent to 16.2 percent. The MET-MFODSR shows much lower overhead than BEEDSR and BEEIP. This is because in the proposed method the data packet delivery rate through the path is much further in the total data information of the network due to the MET packet scheduling approach.

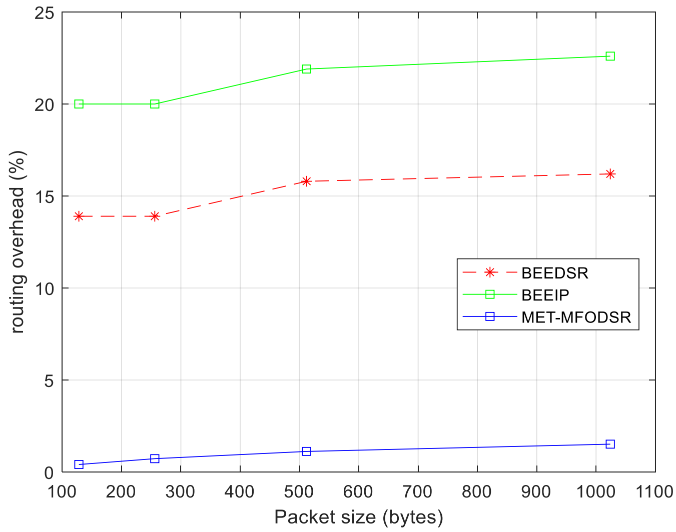


Figure 5.16: Routing overhead ratio versus packet size variation for BEEDSR, BeeIP, and MET- MFODSR.

Figure 5.17 presents the effect of varying the size of the packet on the average energy-consuming for MET-MFODSR, BEEIP. With the increases in packet size, the average energy consumption of all routing approaches increases. When the amount of carried data on the network increases, further energy will be depleted to transfer and broadcasting the packets. In MET-MFODSR, the average energy-consuming increases from 0.1656 percent at 128 bytes to 0.3571 percent at 128 bytes, and is the same way, BEEIP increases from 2.385 percent to 2.689 percent. In BEEDSR increases from 2.381 percent to 2.615 percent. The figure indicates the proposed MET-MFODSR improves the average energy consumption compared with other routing approaches. This is because the proposed algorithm considers the minimum hop distance route and apply the MFO algorithm by considering minimum energy consumption for the node to obtain the optimal route so that lower energy will be depleted.

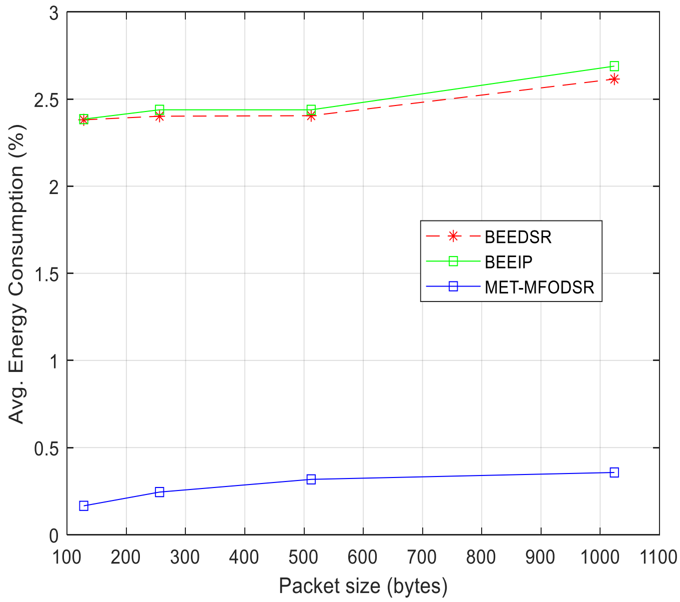


Figure 5.17: Average energy consumption versus packet size variation for BEEDSR, BeeIP, and MET- MFODSR.

Figure 5.18 indicates the impact of packet size variations on the average throughput. the average throughput of MET-MFODSR, BEEDSR, and BEEIP routing methods is increased with the increase of packet size. For proposed MET-MFODSR, the average throughput slightly increases from 200.3 kbps at 128 bytes to 255.2kbps at 1024 bytes, similarly, the increment in BEEIP from 26.09 kbps to 121.9 kbps and BEEDSR from 72.64 kbps to 133.3 kbps. The figure shows that the proposed routing approach offers higher average throughput than BEEIP and BEEDSR. This is due to the advantage of MET packet scheduling which results in the increment in the delivery rate and the execution process of the packets through the neighboring nodes to the sink so that there will be an increment in throughput.

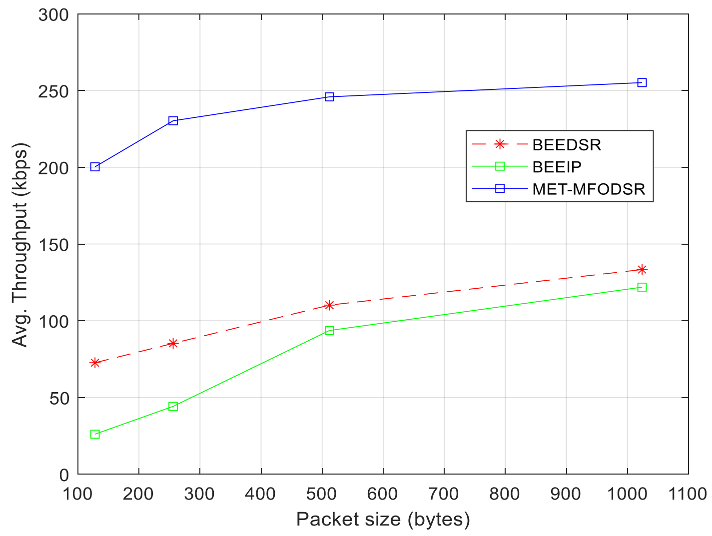


Figure 5.18: Average throughput versus packet size variation for BEEDSR, BeeIP, and MET- MFODSR.

Figure 5.19 depicts the impact of changing the packet size concerning the PDR for MET-MFODSR, BEEIP, and BEEDSR. It is observed that the packet delivery ratio increases slightly as the packet size increases. The figure shows that MET-MFODSR has small increments in the packet delivery rate in the range from 99.91percent at 128 bytes to 99. 9993 percent at 1024 bytes, also, in the same manner, BEEIP has small increment from 99.5 percent to 99.56 percent and BEEDSR from 99.6 percent to 99.65 percent.

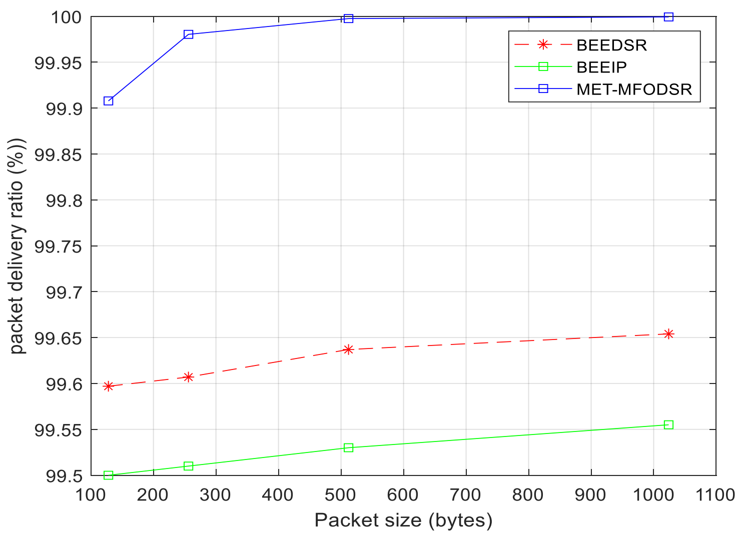


Figure 5.19: Packet delivery ratio versus packet size variation for BEEDSR, BeeIP, and MET- MFODSR.

The result exhibits that the performance of the MET-MFODSR provides a slightly better PDR than BEEIP and BEEDSR routing methods, as it reduces the packet loss by considering the MET packet scheduling to improve the packet delivery and execution through the routing nodes.

Table 5.3 summaries the gathered simulation results details regarding the effect of packet size variations on the performance matrices for MET-MFODSR, BEEDSR, and BeeIP algorithms.

Table 5.3: Packet size variations impact on the performance matrices

Packet size (bytes)	MET-MFODSR	BEEDSR	BEEIP
Average end-to-end delay (ms)			
128	3.72	27.7	31.94
256	4.8	30.51	37.35
512	5.3	38.17	49.78
1024	6.92	60.16	70.85
Routing overhead ratio (%)			
128	0.4081	13.9	20
256	0.7258	13.9	20
512	1.118	15.8	21.9
1024	1.514	16.2	22.6
Average Energy Consumption (%)			
128	0.1656	2.381	2.385
256	0.2446	2.402	2.438
512	0.3175	2.405	2.438
1024	0.3571	2.615	2.689
Average throughput (kbps)			
128	200.3	72.64	26.09
256	230.3	85.26	44.21
512	245.9	110.2	93.65
1024	255.2	133.3	121.9
Packet delivery ratio (%)			
128	99.91	99.6	99.5
256	99.98	99.61	99.51
512	99.9975	99.64	99.53
1024	99.9993	99.65	99.56

CHAPTER 6
CONCLUSION AND FUTURE WORK

Conclusion

The research proposed a novel and efficient version of the DSR approach named MET-MFODSR. The MET-MFODSR is built upon the application of a hybrid approach using MET scheduling and MFO scheme. This improved version of DSR called the (MET-MFODSR) algorithm provides an improved routing mechanism by decreasing the energy consumption, which increases the network lifetime and reduces route failures issue. The simulation results for two different simulation environments displayed that the proposed MET-MFODSR approach provides better performance compared to BEEDSR and BEEIP concerning throughput, average E-to-E D, PDR, overhead ratio, and average energy consumption. Generally, The MET-MFODSR algorithm shows the highest average throughput and PDR versus other existing compared approaches. Also, MET-MFODSR shows less average E-to-E D, routing overhead, and average energy consumption in comparison to BEEDSR and BEEIP algorithms.

Future Work

In terms of the scope of future work, this proposed routing algorithm can be tested and evaluated under WSNs a Vehicular Ad-hoc Networks (VANETs) environments Another suggestion is to apply this hybrid structure of MET scheduling and MFO algorithm with another routing approach to compare it with the proposed MET-MFODSR.

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APPENDICES

APPENDIX 1
ETHICAL APPROVAL LETTER

TO GRADUATE SCHOOL OF APPLIED SCIENCES

Srudent Name: Salem.A. Almazok
Student Id: 20166078

I would like to inform you that the above candidate is one of our postgraduate students in Electrical and Electronic Engineering department he is taking thesis under my supervision and the thesis entailed: **A Novel Dynamic Source Routing (DSR) Protocol based on Minimum Execution Time Scheduling and Moth Flame Optimization (MET-MFO).** The data used in his study was obtained from applying simulation studay of introduced method and does not require any ethical report.

Please do not hesitate to contact me if you have any further queries or questions.

Thank you very much indeed.

Best Regards,

Prof. Dr. Bülent Bilgehan
Faculty of Electrical and Electronic Engineering,
Near East Boulevard, ZIP: 99138
Nicosia / TRNC, North Cyprus,
Mersin 10 – Turkey.
Email: bulent.bilgehan@neu.edu.tr

APPENDIX 2

SIMILIRITY REPORT

AUTHOR	TITLE	SIMILARITY	GRADE	RESPONSE	FILE	PAPER ID	DATE
Salem Almazok	abstract	0%	--	--		1372217651	21-Aug-2020
Salem Almazok	chapter1	0%	--	--		1372114913	21-Aug-2020
Salem Almazok	chapter5	0%	--	--		1372115847	21-Aug-2020
Salem Almazok	conclusion	0%	--	--		1372116057	21-Aug-2020
Salem Almazok	chapter2	3%	--	--		1372115148	21-Aug-2020
Salem Almazok	chapter3	3%	--	--		1372115371	21-Aug-2020
Salem Almazok	chapter4	4%	--	--		1372115568	21-Aug-2020
Salem Almazok	complete thesis	4%	--	--		1372116469	21-Aug-2020

A NOVEL DYNAMIC SOURCE ROUTING (DSR) PROTOCOL BASED ON MINIMUM EXECUTION TIME SCHEDULING AND MOTH FLAME OPTIMIZATION (MET-MFO)

Turnitin result

Prof. Dr. Bülent Bilgehan

Danışman.

APPENDIX 3

CURRICULUM VITAE

PERSONAL INFORMATION

Surname, Name : Almazok, Salem
Nationality : Libyan
Date and Place of Birth : 7 Januanary 1986, Zliten
Marital Status : Married

EDUCATION

Degree	Institution	Year of Graduation
M.Sc.	Griffith University, Department of Electrical and Electronic Engineering	2013
B.Sc.	College of Electronic Technology Bani Walid, Department of Communication Engineering	2007

WORK EXPERIENCE

Year	Place	Enrolment
Oct, 2009- Aug, 2010	Higher Institute of Zliten	Instructor
2014-2016	Faculty Of Engineering, Al-asmarya University	lecturer
2013-2015	Faculty Of Engineering, Misurata University	Associate lecturer
2013-2014	Faculty Of Engineering, Al-mergib University	Associate lecturer

LANGUAGES

Native Arabic

English , speaking and writting

THESIS

Master

- Almazok, S. (2013). *Investigate and Compare the Radiation Efficiency of the Printed Strip Monopole Antenna on FR-4 and on Plastic Sheet Using Wheeler Cap Method.* Unpublished Master Thesis, Griffith University, Department of Electrical and Electronic Engineering, Brisbane, Australia.

Lisans

- Almazok, S. (2007). *Third Generation mobile phone system.* Undergraduate project (B.Sc.), College of Electronic Technology Bani Walid, Department of Communication Engineering. Bani Walid, Libya.

COURSES GIVEN

Undergraduate:

- Computer Applications II, IV (Arabic)
- Analog Communication systems /practicle (Arabic)
- Mobile Communication systems /practicle (Arabic)
- Fundamentals of electric circuits (Arabic and English)
- Electronic I, II (Arabic and English)
- Math I (Arabic)
- Physic I,II (Arabic)

HOBBIES

Reading, Gardening, Sport, Writing Scientific Article.

OTHER INTERESTS

Mobile Ad hoc Networks, Routing Algorithms for Ad hoc Networks, Digital Signal Processing, Learning Basics of Programming Languages, Data Communications and Networking.