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Impact of Deployment Strategies and Mobility Models on MANET Routing Protocols: A Performance Evaluation

Sajjad Abbas[1], Raad A. Qasim[2*], Habeeb Noori Jumaah[1]

[1] University of Telafer, University Presidency, Nineveh 41016, Iraq
[2] Department of Computer Science, Faculty of Education, University of Telafer, Nineveh 41016, Iraq

Corresponding Author Email: raad.a.qasim@uotelafer.edu.iq

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ABSTRACT

Mobile Ad Hoc Networks (MANETs) have become dominant networks in the current technological era due to their importance in the Internet of Things (IoT) and the future of smart cities. The problem with MANET networks is that they are not stable in performance because many factors can be involved (i.e., deployment of mobile nodes, movements of nodes, the nature of the environment, etc.). For instance, selecting a routing protocol is considered a challenging task because it is not the only factor affecting network performance. Despite extensive studies on MANET routing, the combined impact of deployment strategies and mobility models remains underexplored. Hence, in this paper, two routing protocols are developed, designed, and implemented. Moreover, to understand MANET network performance, using OMNeT++, we simulated 105 scenarios combining 3 deployment strategies (Normal, Uniform, Exponential) and 5 mobility models (Correlated Direction, Cauchy Flight, Exponential, Levy Flight, Individual Mobility). Statistical significance was validated via ANOVA ($p < 0.03$). These experiments include combinations of deployment strategies (i.e., Normal, Uniform, and Exponential deployment strategies). Five mobility models are also implemented and incorporated into the design of the simulator and experiments, such as the Correlated Direction mobility model, the Cauchy flight mobility model, the Exponential mobility model, the Levy Flight mobility model, and the Individual Mobility model. Also, two evaluation metrics are involved, namely, coverage area and data spreading. The findings show that the proposed routing protocols outperform the benchmarking, and their results are statistically significant.

1. INTRODUCTION

The population seems to have a lot of interest in wireless computer networks over the years. This innovative technology is currently being used by universities, businesses, military assets, and government and nongovernment groups [1]. As long as, the Internet Protocol (IP), which performs end-to-end delivery of packets based on the IP address of the client and server, is responsible for the development of the modern Internet [2]. In other words, a unique identity and physical placement of a node on the Internet are what an IP address conveys by nature. Particularly, IP assigns the header of each packet, which contains the input and output information and aids in routing and forwarding all packets transmitted over a network, especially wireless networks [3]. Moreover, wireless networks can often be divided into two groups: (a) wireless networks with stable and wired gateways; and (b) wireless networks that should be set up "ad hoc," without the need for a fixed Access Point (AP), and in which all network nodes act as routers by engaging in the discovery and management of routes to other network nodes [4].

According to the study [5], a wireless network called a Mobile Ad Hoc Network (MANET) allows all nodes to spread wherever and independently in any direction and at any speed. Therefore, Ad-hoc besides relocating nodes without a base station, are built. So, it is currently one of the most fascinating investigation points in distant communication. And, the network is gradually changed by these moving nodes, which also distribute information from one node to another. On the Other hand, Ad-hoc networks are complicated spread systems made up of wireless mobile or stationary nodes that can spontaneously and dynamically assemble themselves [6]. Even the mobile ad hoc network has many common applications, such as emergency services, education, entertainment, etc., but it confronts several difficulties, the biggest of which are its limited bandwidth, overhead, quality of service, etc. [7]. Also, MANET has many different specifications including limited bandwidth such as dynamic topology, routing overhead, packet losses, battery constraints and so on [8, 9]. Besides, Transmission Control Protocol (TCP) and IP are the basic protocols that describe the Internet. TCP is considered one of the foremost protocols in the transport layer which was announced in 1981. The primary goal of TCP was to make the connection channel that links two sites over a packet-switching network reliable. The majority of contemporary electronics, including laptops, smartphones, and tablet PCs, now include many network interfaces, including Ethernet ports, WiFi, 4G/LTE cellular data connections, and other options. Researchers looked into the viability of using the secondary network interface for various purposes even though most of the time these devices only use one network adapter at a time. It was suggested to employ many network interfaces concurrently to improve speed and offer redundant connectivity [10]. Also, it is designed to be used as an extremely reliable host-to-host protocol connecting guests in packet-switched device communication networks and in networks that are connected [11]. The main protocol utilized in wireless networks is TCP. TCP has several issues because wireless has taken over as the main component of everyday networks. Because packet losses in wireless networks are regarded as traffic losses in wired networks, throughput is lowered and bandwidth is subsequently wasted. To address this problem, some TCP congestion control techniques have been developed. The development of cellular networks has made it more difficult for earlier congestion control algorithms to offer increased throughput. Because TCP prioritizes balanced network transfer, bandwidth is wasted. By throwing router queues until they drop, the earliest traffic management algorithms in TCP set congestion limits [12].

2. LITERATURE REVIEW

MANETS Networks have many issues, such as Routing, Security and Quality of Service (QoS). Because ad hoc networks have proper connections to other devices in their neighbourhoods, routing is one of the more challenging challenges to address. Multi-hop routing prevents the usage of a default route. To enable in-sequence cooperation between mobile nodes, each node serves as a router and transmits packets from other nodes. Moreover, data transmission is far more vulnerable than a cable link. User error can be added to routing packets, leading to routing loops, lengthy timeouts, and ads for erroneous or outdated routing changes. Ad hoc networks need to address a few security-related problems before they can be considered an acceptable option. Level of Service (QoS) The developers have a difficult challenge because an ad hoc network's topology is likely to alter frequently. It is extremely difficult to reserve resources and maintain a specific level of service while the network environment is continually changing [13].

TCP-DOOR (Out of Order Delivery Event Protocol) - TCP-DOOR (Out of Order Delivery Event Protocol) tried to improve TCP's performance in ad hoc networks by detecting and responding appropriately to out-of-order packet delivery events. As a result, TCP-DOOR avoids using the congestion control mechanism, which is not required by definition. OOO (out-of-order) typically occurs when a sent pack or package arrives at the destination after the subsequent Due to route changes in Ad-Hoc Networks, out-of-order might happen multiple times during a single TCP session. As a result, ordering metadata is included in TCP data packets and TCP ACKs to efficiently detect out-of-order delivered packets [14].

General problems: The primary function of TCP DOOR is to identify OOO (out-of-order) conditions and signal the occurrence of a recent route change event. However, out-of-order can be identified after the routes had recovered from failures or faults. As a result, TCP-DOOR is not as responsive and exact as the feedback-based approach protocol, which can accurately account for and return to the sender(s) at the outset regardless of whether route failures or congestion have happened. Additionally, TCP DOOR may not function properly with different multi-path routings since they could result in OOO. As a result, it is recommended that TCP-DOOR be used in place of or in addition to the feedback scheme method to improve Network throughput in MANETs, but only in cases where those protocols or feedback-based approaches are unavailable [14].

Fazio et al. [15] presented the signal-based routing mechanism, which would be obtained from MAC for multi-channel MANETs, in response to the radio signal-based approach. This work's main objective is to reduce co-channel noise and improve system performance. The findings of the experiment demonstrated that the routing algorithm improves network performance over conventional protocols. As a result, Ejmaa et al. [16] suggested a topology-based protocol called connection factor routing protocol in the topology-based method (DCFP). This study's main suggestion is a neighborhood rate-based routing metric. The DCFP protocol, as opposed to conventional protocols, improves operational efficiency and energy efficiency, according to the results of experiments.

Quy et al. [17] consequently presented a new combined-metric-based methodology for the traffic-based approach. The goal of this work is to improve system performance by providing a new metric that combines three separate metrics—hops quantity, link status, and queue. Additionally, recent studies [18] demonstrate that the traffic network-based method and the MANETs performance boost study field, in general, are quite fascinating and draw a strong interest from both academia and technology.

Epidemic Procedures: Since the epidemic protocol is essentially flooding-based, any contact nodes that have messages copy them to them if they do not already have them. To accomplish this, nodes first trade summary vectors, which are lists of the messages they will exchange when they get in touch. Then, after checking the list of data it has not yet received, each node asks the other node for the messages [19]. The epidemic routing protocol can ensure the highest transport probability and average delay if the buffer size is infinite. Since the epidemic protocol makes numerous duplicates of a message and the buffer size is restricted, improved management strategies for battery and buffer energy have been presented. For instance, a node transfers data to certain other nodes only if the number of neighbour contact nodes surpasses a preset threshold value, that is, n, in an energy-efficient n-epidemic routing protocol [20].

In the study by Pastor-Satorras et al. [21], the authors used trace-file and random waypoint mobility models to thoroughly examine the performance of four epidemic routing protocol categories: P-Q epidemic, epidemic using time-to-live (TTL), and an epidemic with contact counter (EC). The authors then put forth three improved schemes—dynamic TTL, EC + TTL, and continuous immunity—and demonstrated how they may increase delivery probability while dramatically lowering buffer occupancy level in the case of the cumulative immunity method.

Protocol for PHET. In practical application contexts, the PRoPHET protocol makes use of nonrandom movement and contact patterns to copy data to other nodes and boost routing performance [22]. In other words, the PRoPHET strategy is predicated on the idea that a node is more likely to visit a place or make contact with another node if it has done so previously. To do this, each node must declare "delivery predictability" for every node it contacts. The spectrum of distribution unreliability value is specified as 0PA, B 1. Node A to node

B's delivery predictability is marked by PA, B.

One study proposes an enhancement to the Ad hoc On-Demand Distance Vector (AODV) routing protocol by integrating the location-based capabilities of the Distance Routing Effect Algorithm for Mobility (DREAM). This approach improves QoS by maintaining precise records of each node's position, optimizing routing decisions, and reducing overhead [23]. Another improvement in MANET routing involves a novel multipath routing method based on the Multi-Hop Routing (MHR) technique. The Priority-Based Dynamic Routing (PBDR) mechanism adapts to network dynamics by considering node mobility parameters, thereby reducing link failures and enhancing QoS [24].

To further address QoS challenges, a multi-objective routing model has been proposed that integrates a link trust mechanism, allowing for more accurate trust assessments. This model enhances energy efficiency and security in routing decisions, ensuring a balance between performance and reliability [25]. Another trust-based approach is the Improved Energy Efficient Honeycomb-based Routing (IEEHR) method, which focuses on energy efficiency while maintaining trust levels in MANET routing, contributing to more secure and reliable data transmission [26]. Security is also a major concern in MANETs, and one study specifically examines certificate revocation schemes for providing trust-based malicious node detection. The research enhances security by effectively managing certificate revocations, preventing unauthorized access, and improving overall QoS [27].

Routing metrics play a crucial role in optimizing QoS, and recent research highlights the importance of mapping QoS requirements to routing parameters. By incorporating these factors into the cost function, QoS can be significantly improved, particularly for hypermedia applications in MANETs [28]. Additionally, meta-heuristic algorithms have been explored to enhance QoS in MANETs. A comprehensive review discusses various approaches that focus on security, energy efficiency, and routing, offering an in-depth analysis of existing optimization techniques and their impact on MANET performance [7].

Machine learning has also been applied to MANET routing to enhance security and performance. A proposed ML-based AODV Routing Protocol (ML-AODV) mitigates flooding and blackhole attacks by leveraging intelligent decision-making mechanisms. This enhances routing security and ensures stable network performance [29]. Blockchain technology has also been explored for securing MANETs, with a study proposing a blockchain-based routing protocol that safeguards control and data flow against various cyber threats. By generating a hash function for every transaction, this protocol ensures node authentication and data integrity in a decentralized manner [30].

Finally, a study on QoS-aware and social-aware multimeric routing introduces a new protocol for video-streaming services over MANETs. This approach integrates both QoS and social metrics to optimize routing decisions, ensuring a balance between performance and trust among users. The study highlights the importance of user relationships in forming efficient data-forwarding paths, making it a promising solution for media streaming applications in MANETs [31].

The research [32] demonstrated that using different network topologies, such as Star, Bus, Ring, Tree, and so on, can lead to many issues as shown in Table 1.

Table 1. Different network topologies [32]

Parameters	Bus	Star	Ring	Mesh	Tree
Installation	easy	easy	difficult	difficult	easy
Cost	inexpensive	expensive	moderate	expensive	less
Flexible	yes	yes	no	no	yes
Reliability	moderate	high	high	high	moderate
Extension	easy	easy	easy	poor	easy
Robust	no	yes	no	yes	no

3. LITERATURE GAPS AND CONTRIBUTION

According to the literature, many gaps need to be filled in terms of improving the routing techniques in MANET networks. Hence, in this paper, two routing protocols are developed, designed, and implemented. Moreover, to understand MANET network performance, 105 experiments are designed and implemented as scenarios. These experiments include combinations of deployment strategies (i.e., Normal, Unifor, and Exponential deployment strategies). Five mobility models are also implemented and incorporated into the design of the simulator and experiments such as the Correlated Direction mobility model, the Cauchy Flight mobility model, the Exponential mobility model, the Levy Flight mobility model, and the Individual Mobility model.

4. RESEARCH METHOD

In this section, the main routing protocols used in this dissertation are described in detail. We also present the details of the design and implementation in terms of the following:

- Routing protocols.
- The mobility models.
- Nodes deployment strategies.
- Evaluation metrics.
- Incorporate all together in the designed simulator.

5. ROUTING PROTOCOLS

The protocols involved in this dissertation work are under TCP in MANET networks. These protocols were coded and implemented to be adequate for this work as follows:

PRoPHET Routing Protocol: This protocol was coded and implemented to be adequate for this paper. It mainly depends on the value of delivery predictability when sending a message from the sender to the receiver. Algorithm 1 describes the main steps of the implementation.

Algorithm 1: PRoPHET Routing Protocol

INPUT: Sender nodes (S), neighbors (N)
OUTPUT: Selected receiver node (Ni)

1. FOR each neighbor Ni ∈ N of S DO
2. Update delivery predictability P(S, Ni)
3. IF P(S, Ni) < 0.1 THEN
4. SET P(S, Ni) ← 0.5
5. DETECT Ni as receiver
6. SEND message (S → Ni)
7. EXCHANGE P(S, Ni) between S and Ni
8. INCREMENT total_messages
9. STOP

Spray and Wait Routing Protocol: The implementation of this routing protocol is shown in Algorithm 2 which is included in the framework of the designed simulator.

Algorithm 2: Spray & Wait Routing Protocol

INPUT: Sender nodes (S), neighbors (N)
OUTPUT: Message sent to receiver node
1. FOR each neighbor Ni ∈ N of S DO
2. IF S.messages > 1 THEN
3. SEND message to Ni
4. SET S.messages ← S.messages - 1
5. INCREMENT total_exchanged_messages
6. END

Binary Spray and Wait Routing Protocol: It is similar to the previous one and is considered an updated version. The difference in the implementation between this updated protocol and the previous one is that the number of messages is divided by 2 when delivering a message from the sender to the receiver.

Gradient Routing Protocol: The gradient routing protocol was implemented in the designed simulator and the general steps of the implementation can be shown in Algorithm 3.

Algorithm 3: Gradient Routing Protocol

INPUT: Sender node (S), neighbor nodes (N)
OUTPUT: Selected receiver node (Ni)
1. FOR each neighbor Ni ∈ N of S DO
2. IF Ni has delivered a message recently THEN
3. IF F(S) < F(Ni) THEN // F = message frequency
4. SELECT Ni as receiver
5. SEND message (S → Ni)
6. INCREMENT total_exchanged_messages
7. END IF
8. END IF
9. END FOR

Probabilistic Flooding Routing Protocol: This routing protocol was implemented in the designed simulator with general steps shown in Algorithm 4.

Algorithm 4: Probabilistic Flooding Routing Protocol

INPUT: Sender node (S), neighbor nodes (N), threshold Delta ∈ (0,1)
OUTPUT: Message transmission to receiver node(s)

1. FOR each neighbor Ni ∈ N of S DO
2. r ← GENERATE_RANDOM_FLOAT(0,1)
3. IF r < Delta THEN
4. SEND message to Ni
5. UPDATE_PROBABILITY(Delta) // Adjust Delta based on network conditions
6. INCREMENT total_exchanged_messages
7. END IF
8. END FOR

All the above-mentioned protocols were fully configured to work in a MANET environment. In this paper, two of the considered routing protocols were developed to provide more efficient performance. The developed routing protocols can be described as follows:

5.1 Home-Location-Aware gradient routing protocol (Proposed_1)

The main idea behind developing this protocol is to merge the features of the protocol with the mobility information of nodes. When forwarding messages from one node to another one, the cost of routing will be added to the message. The cost will be estimated based on the distance between the current position of the sender and the current position of the destination (Eq. (1)).

$$(\widehat{Cost})_{routing} = Cost_{(distance\ between\ sender\ and\ reciever)} \quad (1)$$

In addition, another cost will be added to the total routing cost, which is the home position (starting point) of the source and target nodes as follows:

Sender Home: The home position of the sender node.

Receiver Home: The home position of the potential receiver node.

Costsender-reciever: The cost of the distance between the sender and the potential receiver.

$$(\widehat{Total})Cost_{routing} = (\widehat{Cost})_{routing} + Cost_{(sender-reciever)} \quad (2)$$

This is based on a concept inspired by the nature of the movement patterns on objects. These two costs will be calculated for each neighbour node of the sender. Then, the receiver will be selected based on the minimum cost between the sender and its neighbours:

$$Candidate\ Reciever \in Minimum\left((\widehat{Total})Cost_{routing}\right) \quad (3)$$

Then, the message will be sent to the candidate receiver node. Algorithm 5 describes the steps of the Proposed_1 routing protocol.

Algorithm 5: Home-Location-Aware Gradient Routing Protocol (Proposed_1)

INPUT: Sender node (S), neighbor nodes (N), home positions (S_h, N_h)
OUTPUT: Selected receiver node (N_i)

1. FOR each neighbor N_i ∈ N of S DO
2. IF N_i has delivered a message recently THEN
3. IF F(S) < F(N_i) THEN ▷ F = message delivery frequency
4. $cost_1$ ← distance(S.position, N_i.position)
5. $cost_2$ ← distance(S_h, N_{ih})
6. total_cost ← $cost_1$ + $cost_2$ ▷ Equation (2)

```
        IF total_cost = min_cost THEN
            selected_node ← Ni
        END IF
      END IF
  END IF
END FOR

IF selected_node exists THEN
  SEND message (S → selected_node)
  INCREMENT total_exchanged_messages
END IF
```

5.2 Home-Location-Aware PRoPHET routing protocol (Proposed_2)

The history of encounters between MANET pairs is kept in each node. Whenever a node has a message, it first checks its neighbours, then, the message is sent to one of them that has the lowest distance between their home positions. If two nodes have the same distance between their home positions, then, the node with the highest frequency of encounters will be considered the receiver. This procedure is repeated until getting the destination. Equations 1, 2, and 3 were used to support the selection process of the candidate receiver node.

Algorithm 6: Home-Location-Aware PRoPHET Routing Protocol (Proposed_2)

INPUT: Sender node (S), neighbor nodes (N), home positions (S_h, N_h)
OUTPUT: Selected receiver node (N_i)

```
FOR each neighbor Ni ∈ N of S DO
  UPDATE delivery_predictability P(S, Ni)
  IF P(S, Ni) < 0.1 THEN
     SET P(S, Ni) ← 0.5
     cost1 ← distance(S.position, Ni.position)
     cost2 ← distance(Sh, Nih)
     total_cost ← cost1 + cost2  ▷ Equation (2)
     IF total_cost = min_cost THEN
        selected_node ← Ni
      END IF
  END IF
END FOR
IF selected_node exists THEN
  SEND message (S → selected_node)
  EXCHANGE P(S, selected_node) with selected_node
  INCREMENT total_exchanged_messages
END IF
```

6. MOBILITY MODELS

Many mobility models are available in the literature for simulating the movement patterns of nodes. Each model can simulate a particular scenario, taking into account the carrier of the nodes (i.e., automobiles, humans, or any specific moving objects that can carry nodes). The mobility models involved in the experiments can be listed as follows:

Correlated Direction Model: The implementation of this mobility model was performed and incorporated into the environment. The design of this model was based on the following equations:

$$Direction\ (random_{float}) = 360 \tag{4}$$

$$Rotate\ (random_{Normal})\ of\ stdevAngle = 0 \tag{5}$$

$$jump_{Size} = FlightLength \tag{6}$$

Exponential Model: The jump size in this model is calculated based on Eq. (7):

$$Jump_{size} = X^{-\propto} * e^{-x*\lambda} \tag{7}$$

where, $\propto$ is the scaling parameter, X is the locations parameter, and λ is the moving cutoff parameter.

Cauchy Flight Model: In this model, the jump size is designed according to Eq. (8).

$$Jump_{size} = X_0 + \gamma \tan\left(\phi * \left(p - \tfrac{1}{2}\right)\right) \tag{8}$$

where, γ is the scale parameter and X is the location parameter.

Levy Flight Model: The jump size is calculated based on Eq. (9) as follows:

$$Jump_{size} = Min(x) * (1 - r)^{\left(-\frac{1}{\propto - 1}\right)} \tag{9}$$

where, r denotes the probability of distributing a node.

Individual Mobility (IM) Model: Based on the work [33], the IM model works based on two mechanisms; a) Exploration: which means that a node can visit more locations as time passes and follows Eq. (10):

$$L_{new} = aX^{-\lambda} \tag{10}$$

where, L_{new} is the probability of going to a new location, a and λ are the parameters that were used to control the move (jump), and X is the number of visited locations by a node.

The other mechanism is b) preferential return, which means that a node always returns to the most visited locations in the past as shown in Eq. (11).

$$L_{return} = 1 - L_{new} \tag{11}$$

where, L_{return} denotes the probability to return to the home location. It can be seen that the return probability is a complementary probability of a node visiting a new location within the simulation environment.

7. SIMULATION ENVIRONMENT

The environment is designed to imitate real-world MANET network situations such that the environment should be divided into blocks (e.g., regions in cities) where each block represent a building or any space. Also, a real environment should have dimensions that nodes of MANET cannot pass (boundaries). The environment has 20×30 km which reflects a huge environment with the center of the coordinates of (0,0). During the simulations, each block starts with the black colour. Whenever a MANET node visits a block, the colour gradually turns to green until it ends with white colour if the block has been visited 50 times. The purpose of involving this feature is to see which regions have more visits aiming to have some knowledge about the most covered regions by the mobile nodes. Moreover, within the environment, each node moves from one block to another block in one step (tick).

8. NODES DISTRIBUTION

One of the most important features of the designed simulator is its ability to deploy nodes in the environment in different strategies as follows:

Normal Deployment: When it is needed to deploy network nodes based on a normal distribution pattern. Deploying nodes under this strategy means that nodes are lightly deployed from the center of the environment, reaching the borders. This case reflects a real-world environment when considering our cities.

Uniform and Lattice Deployment: This strategy means that nodes are deployed based on setting the same distance between each pair of nodes. This scenario is useful when considering counties and villages for MANET networks. The main difference between Lattice and Uniform deployment strategies is that in the Uniform strategy, the nodes are scattered.

Exponential Deployment: It is the most common scenario for node deployment, especially when simulating crowded cities where nodes are highly focused in the center, and significantly decrease when approaching the edges of the environment.

The aforementioned node deployment strategies were involved in the experiments of this dissertation because assuming such scenarios provide more reliable simulations that imitate real-world situations.

9. EVALUATION METRICS

The evaluation of MANET performance was measured using two metrics. These metrics can be described as follows:

Coverage area: Nodes in MANET move within the environment, as these nodes move, they cover more areas by their communication range. The percentage of the covered area is considered an important indicator of the uncovered areas in the environment that need to be considered as gaps in the environment that need more attention by the network architect.

Data Spreading: It is defined as the percentage of the area that is covered by the data messages.

10. RESULTS AND DISCUSSIONS

The method we followed in designing the experiments of this work was based on considering 15 scenarios in three groups as follows: Scenarios 1 to 5 use all the routing protocols and the mobility models with a normal distribution. Scenarios 6 to 10 use all the routing protocols and the mobility models with Uniform distribution. Finally, Scenarios 11 to 15 use all the routing protocols and the mobility models with the Exponential distribution.

10.1 Performance evaluation of Scenarios 1 to 5

Based on the designed scenarios, the performance of each scenario was evaluated for the two proposed routing protocols and benchmarked with the other protocols used. Figures 1 and 2 show the performance of each protocol in terms of coverage area and data spreading metrics. It can be observed that the performance of the proposed routing protocols outperformed the other protocols in terms of both metrics. Furthermore, in the five scenarios, the Proposed_1 routing protocol outperformed the Proposed_2 routing protocol.

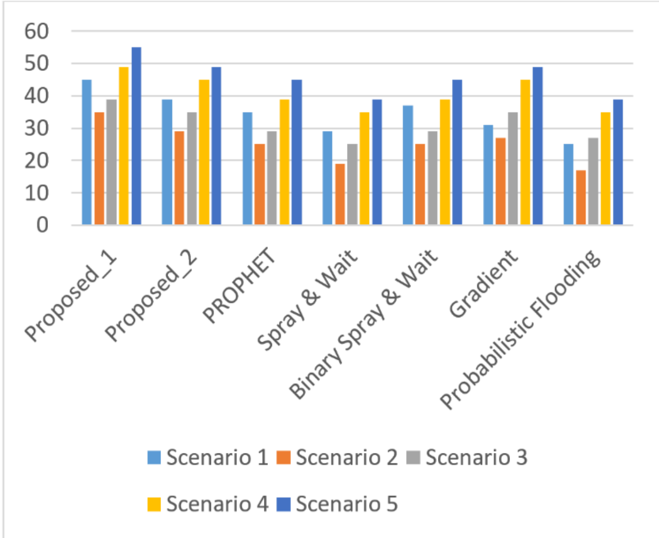

Figure 1. Coverage area performance across 1-5 scenarios

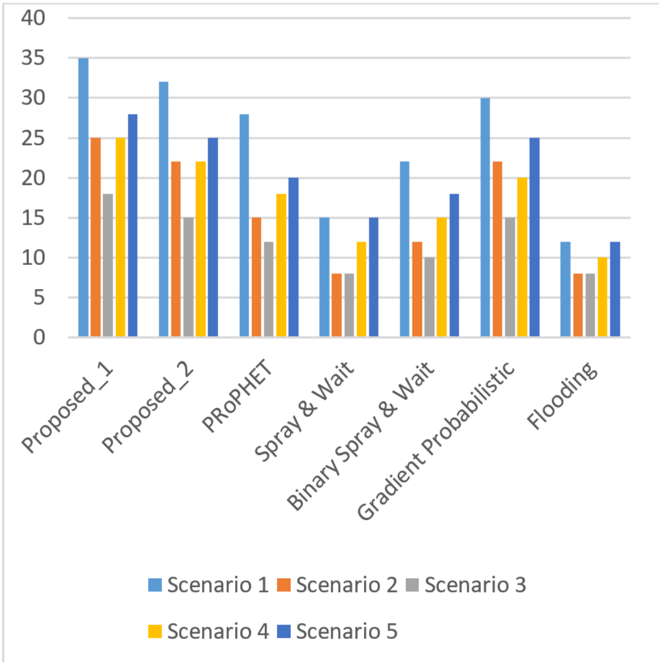

Figure 2. Data spreading performance across 1-5 scenarios

10.2 Performance evaluation of Scenarios 6 to 10

Based on the designed scenarios, the performance of each scenario was evaluated for the two proposed routing protocols and benchmarked with the other protocols used. Figures 3 and 4 show the performance of each protocol in terms of coverage area and data spreading metrics. It can be observed that the performance of the proposed routing protocols outperformed the other protocols in terms of both metrics. According to the figures, the best performance obtained was when using the Uniform distribution and IM mobility model. It should be mentioned that in all five scenarios, the IM mobility model reflects better performance compared to the other mobility models. Also, in the five scenarios, the Proposed_1 routing protocol outperformed the Proposed_2 routing protocol.

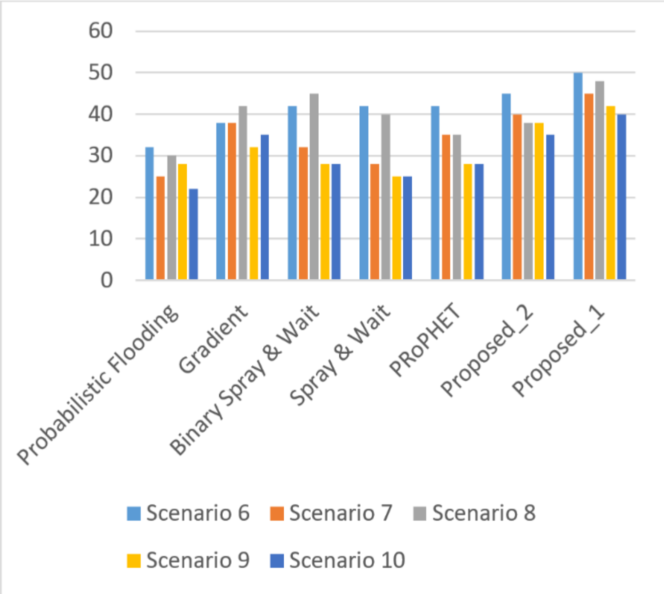

Figure 3. Coverage area performance across 6-10 scenarios

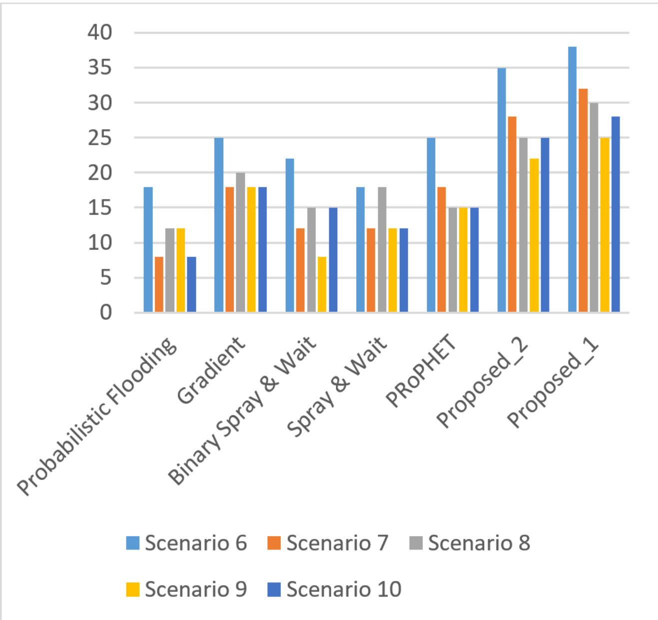

Figure 4. Data spreading performance across 6-10 scenarios

10.3 Performance evaluation of Scenarios 11 to 15

Based on the designed scenarios, the performance of each scenario was evaluated for the two proposed routing protocols and benchmarked with the other protocols used. Figures 5 to 6 show the performance of each protocol in terms of coverage area and data spreading metrics. It can be observed that the performance of the proposed routing protocols outperformed the other protocols in terms of both metrics. According to the figures, the best performance was obtained when using the Exponential distribution and IM mobility model. The exponential distribution deploys nodes in a way that concentrates nodes in the center of the environment and gradually decreases towards the borders of the environment and causing the nodes to be high in the communication range of each other and making the spreading of data intensive. It should be mentioned that in all five scenarios, the IM mobility model reflects better performance compared to the other mobility models. The reason behind this is that the IM model considered MANET nodes to be carried by humans. The nature of human movement patterns considers visiting more locations in an environment, which leads to covering more areas and spreading data to more nodes. Furthermore, in the five scenarios, the Proposed_1 routing protocol outperformed the Proposed_2 routing protocol.

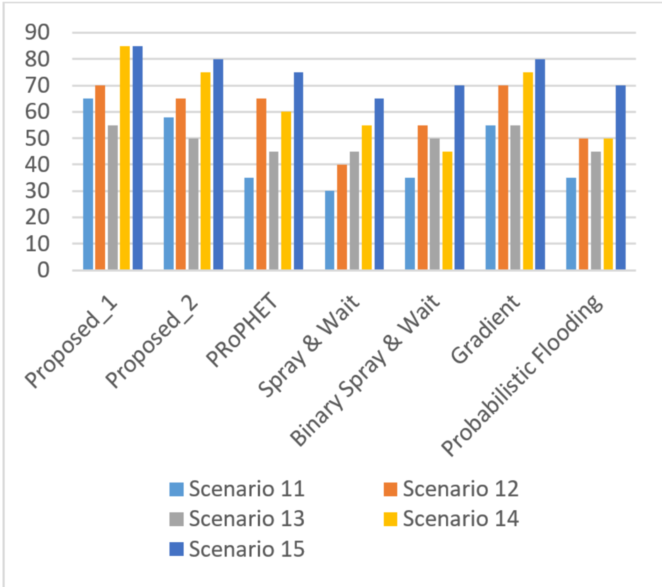

Figure 5. Coverage area performance across 11-15 scenarios

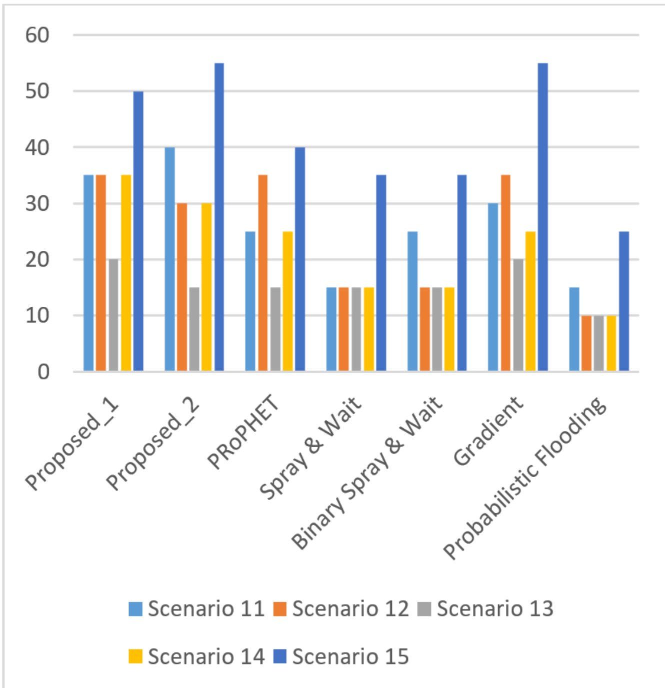

Figure 6. Data spreading performance across 11-15 scenarios

11. DEVELOPED ROUTING PROTOCOLS VERIFICATION

To verify the developed routing protocols, the following verifications were performed:

Proposed_1 Performance Verification

The performance was measured for each group in the experiments in a way that considers each mobility model with each single deployment strategy. The collective performance of coverage area and data spreading was calculated after performing a normalizing process.

Collective Performance =
Norm*(Performance_CoverageArea) +*
Norm*(Performance_DataSpreading)*

Then, the collective performance was used in measuring the performance. Therefore, the regression model is built as follows:

$Proposed\_1_{CollectivePerformance}$ =
$Performance_{CorrelatedDirection\_Normal}$(Proposed_1) +
$Performance_{Exponential\_Normal}$(Proposed_1) +
$Performance_{CauchyFlight\_Normal}$(Proposed_1) +
$Performance_{LevyFlight\_Uniform}$(Proposed_1) +
$Performance_{IM\_Uniform}$(Proposed_1) +
$Performance_{CorrelatedDirection\_Uniform}$(Proposed_1) +
$Performance_{Exponential\_Uniform}$(Proposed_1) +
$Performance_{CauchyFlight\_Uniform}$(Proposed_1) +
$Performance_{LevyFlight\_Uniform}$(Proposed_1) +
$Performance_{IM\_Uniform}$(Proposed_1) +
$Performance_{CorrelatedDirection\_Exponential}$(Proposed_1) +
$Performance_{Exponential\_ Exponential}$(Proposed_1) +
$Performance_{CauchyFlight\_ Exponential}$(Proposed_1) +
$Performance_{LevyFlight\_ Exponential}$ (Proposed_1)+
$Performance_{IM\_ Exponential}$(Proposed_1)

Also, two hypothesis tests were considered as follows:

Null Hypothesis (*H0*): The mean collective performance of the mobility models and deployment strategies for the Proposed_1 is equal:

μ(*Correlated Direction-Normal*) = $\mu(Exponential - Normal)$ = $\mu(CauchyFlight - Normal)$ = $\mu(LevyFlight - Normal)$ = $\mu(IM - Normal)$ = μ(*Correlated Direction-Uniform*) = $\mu(Exponential - Uniform)$ = $\mu(CauchyFlight - Uniform)$ = $\mu(LevyFlight - Uniform)$ = $\mu(IM - Uniform)$ = μ(*Correlated Direction-Exponential*) = $\mu(Exponential - Exponential)$ = $\mu(CauchyFlight - Exponential)$ = $\mu(LevyFlight - Exponential)$ = $\mu(IM - Exponential)$

Alternative Hypothesis (*H1*): The mean collective performance of the mobility models and deployment strategies for the Proposed_1 is not equal:

μ(*Correlated Direction-Normal*) ≠ $\mu(Exponential - Normal)$ ≠ $\mu(CauchyFlight - Normal)$ ≠ $\mu(LevyFlight - Normal)$ = $\mu(IM - Normal)$ ≠ μ(*Correlated Direction-Uniform*) ≠ $\mu(Exponential - Uniform)$ ≠ $\mu(CauchyFlight - Uniform)$ ≠ $\mu(LevyFlight - Uniform)$ ≠ $\mu(IM - Uniform)$ ≠ μ(*Correlated Direction-Exponential*) ≠ $\mu(Exponential - Exponential)$ ≠ $\mu(CauchyFlight - Exponential)$ ≠ $\mu(LevyFlight - Exponential)$ ≠ $\mu(IM - Exponential)$

The confidence level considered for the test is 97%, which means the value of (α) is 0.03.

According to Table 2, it can be observed that the p-value is significantly less than the significance level (0.03). This means we cannot accept the Null Hypothesis of equal means. Therefore, the result of the Proposed_1 is statistically significant and each mobility model and deployment strategy has a significant impact on the whole performance of the proposed algorithm.

Proposed_2 Collective Performance Verification

The performance was measured for each group in the experiments in a way that considers each mobility model with each single deployment strategy. the collective performance of the coverage area and data spreading was calculated after performing a normalizing process.

Table 2. ANOVA Single Factor for verifying the collective performance of Proposed_1 in terms of deployment strategies and mobility models

SUMMARY						
Groups	**Count**	**Sum**	**Average**		**Variance**	
Comb_1	15	990	66		285	
Comb_2	15	934	62.2666667		304.638095	
ANOVA						
Source of Variation	**SS**	**df**	**MS**	**F**	**P-value**	**F**
Between Groups	104.533333	1	104.533333	0.35456777	0.55632146E-05	5.22753455
Within Groups	8254.93333	28	294.819048			
Total	8359.46667	29				

Table 3. ANOVA Single Factor for verifying the collective performance of Proposed_2 in terms of deployment strategies and mobility models

SUMMARY						
Groups	**Count**	**Sum**	**Average**		**Variance**	
Comb_1	15	644	42.9333333		209.92381	
Comb_2	15	591	39.4		172.828571	
ANOVA						
Source of Variation	**SS**	**df**	**MS**	**F**	**P-value**	**F**
Between Groups	93.6333333	1	93.6333333	0.48926323	0.49002674E-06	5.22753455
Within Groups	5358.53333	28	191.37619	-	-	-
Total	5452.16667	29	-	-	-	-

CollectivePerformance=***Norm****(Performance_CoverageArea) +* ***Norm****(Performance_DataSpreading)*

Then, the collective performance was used in measuring the performance. Therefore, the regression model is built as follows:

$Proposed\_2_{CollectivePerformance}$ =
$Performance_{CorrelatedDirection\_Normal}$(Proposed_2) +
$Performance_{Exponential\_Normal}$(Proposed_2) +
$Performance_{CauchyFlight\_Normal}$(Proposed_2) +
$Performance_{LevyFlight\_Uniform}$(Proposed_2) +
$Performance_{IM\_Uniform}$(Proposed_2) +
$Performance_{CorrelatedDirection\_Uniform}$(Proposed_2) +
$Performance_{Exponential\_Uniform}$(Proposed_2) +
$Performance_{CauchyFlight\_Uniform}$(Proposed_2) +
$Performance_{LevyFlight\_Uniform}$(Proposed_2) +
$Performance_{IM\_Uniform}$(Proposed_2) +
$Performance_{CorrelatedDirection\_Exponential}$(Proposed_2) +
$Performance_{Exponential\_Exponential}$(Proposed_2) +
$Performance_{CauchyFlight\_Exponential}$(Proposed_2) +
$Performance_{LevyFlight\_Exponential}$(Proposed_2)+
$Performance_{IM\_ Exponential}$(Proposed_2)

Also, two hypothesis testing were considered as follows:

Null Hypothesis (*H0*): The mean collective performance of the mobility models and deployment strategies for the Proposed_2 is equal:

μ(*Correlated Direction-Normal*) = μ($Exponential - Normal$) = μ($CauchyFlight - Normal$) = μ($LevyFlight - Normal$) = μ($IM - Normal$) = μ(*Correlated Direction-Uniform*) = μ($Exponential - Uniform$) = μ($CauchyFlight - Uniform$) = μ($LevyFlight - Uniform$) = μ($IM - Uniform$) = μ(*Correlated Direction-Exponential*) = μ($Exponential - Exponential$) = μ($CauchyFlight - Exponential$) = μ($LevyFlight - Exponential$) = μ($IM - Exponential$)

Alternative Hypothesis (*H1*): The mean collective performance of the mobility models and deployment strategies for the Proposed_2 is not equal.

μ(*Correlated Direction-Normal*) ≠ $\mu(Exponential - Normal) \neq \mu(CauchyFlight - Normal) \neq \mu(LevyFlight - Normal) = \mu(IM - Normal) \neq$ μ(*Correlated Direction-Uniform*) ≠ $\mu(Exponential - Uniform) \neq \mu(CauchyFlight - Uniform) \neq \mu(LevyFlight - Uniform) \neq \mu(IM - Uniform) \neq$ μ(*Correlated Direction-Exponential*) ≠ $\mu(Exponential - Exponential) \neq \mu(CauchyFlight - Exponential) \neq \mu(LevyFlight - Exponential) \neq \mu(IM - Exponential)$

The confidence level considered for the test is 97%, which means the value of (α) is 0.03.

According to Table 3, it can be observed that the p-value is significantly less than the significance level (0.03). This means we cannot accept the Null Hypothesis of equal means. Therefore, the result of the Proposed_2 is statistically significant, and each mobility model and deployment strategy have a significant impact on the whole performance of the proposed algorithm.

12. CONCLUSIONS

According to the results presented, it can be concluded that MANET networks have many factors that can directly affect the whole performance of the network. Routing protocols are not enough to ensure better performance. The deployment strategies can play a significant role in obtaining more reliable performance. As the results showed, when varying the deployment strategy of nodes, the performance is directly affected. According to the results, better performance was obtained when using an exponential deployment strategy. This is because in this strategy, nodes are focused on particular areas and the distance between them is small causing them to be in communication range of each other most of the time. In reality, this phenomenon reflects a city whose population is concentrated in the center. As a result, the simulation performed in this dissertation reflected a real-world situation, which makes this work more reliable for adoption in real-world scenarios.

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