Mobility Models Based AODV Mobile Ad Hoc Networks Performance Evaluation Using NetSim Simulation Program

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***Abstract*—Mobile Ad Hoc Networks (MANETs) are self-organizing, wireless networks devoid of any infrastructure in which mobile nodes can form connections and transmit messages cooperatively. Their adaptive nature and ability to self-configure makes them a viable solution in an Internet of Things (IoT) environment, while node mobility does impose some challenges in terms of route stability, packet loss, and energy wastage. This study examines how two different mobility models affect the performance of the Ad-Hoc on-Demand Distance Vector (AODV) routing protocol in the NetSim environment version 14.2. The effect of using two different speeds (10 m/s and 50 m/s) for both models and the AODV routing protocol were put to the test by observing five QoS (quality of service) metrics: Throughput, end-to-end delay, Packet Delivery Ratio (PDR), routing overhead, and energy consumption. From the simulation results, it is concluded that node mobility will have a major affect routing behavior and energy use. Overall, the random waypoint mobility model provides the highest throughput and PDR along with moderate delay and energy consumption, as compared to random walk and no-mobility solutions. All mobility models (including no-mobility) exhibited degraded performance at 50 m/s due to excessive link breakage; however random waypoint provided the most overall balance in performance. In summary, these findings show that moderate, structured node mobility will enhance route stability, and the overall transport protocol performance for MANETs. These findings add value to potential designs for mobile network optimization in the future IoT.**

***Index Terms*—Ad-Hoc on-Demand Distance Vector (AODV), Mobile Ad Hoc Network (MANET), mobility, NetSim, performance**

I. INTRODUCTION

Research on ad hoc networks include wireless mesh networks, sensor networks, and mobile ad hoc networks. Users may remotely access their information owing to the extensive networking flexibility provided by wireless technology. Ad-hoc networks provide wireless connectivity among nodes without the need for infrastructural support or management. The Internet of Things (IoT) is an advanced technology facilitated by heterogeneous networks and effective solution that enables real-time communication between physical objects [1, 2]. Energy efficiency, multicasting, routing and maintenance, clustering, and mobility management are emerging fields of research within Mobile Ad-Hoc Network (MANET). In a MANET, each node functions as a router and autonomously configures itself [3]. MANET offers a pathway for diverse communication systems rooted in IoT, exhibiting strong capabilities for a multitude of applications across many fields, therefore, MANETs are essential for controlling node mobility in IoT. It facilitates self-assembly and network connectivity in IoT-based devices. Routing difficulties make networking in such a system very complex. The networking of IoT ad hoc systems relies on MANET routing protocols [4]. The aim of this study is to examine the effect of mobility models (random walk, random waypoint) on different QoS (quality of service) parameters with two velocity (10 m/s and 50 m/s) with MANET based on AODV (ad-hoc on-demand distance vector) routing protocol using NetSim v14.2 network simulation software developed by Tetcos. It is widely used in research, academia, and industry to design, analyze, and visualize computer networks, wireless systems, and communication protocols—without requiring physical hardware.

The reminder of paper is organized as follows: Section II reviews the related work, Section III presents some theoretical concepts, Section IV describes the research methodology, Section V discusses the results and analysis and Section VI concludes the paper.

II. RELATED WORKS

Recent research on MANETs had emphasized the influence of node mobility models on routing performance and network stability. Studies have compared classical routing protocols such as AODV, DSR (dynamic source routing), and OLSR (optimized link state routing protocol) under different mobility patterns to understand their effect on QoS metrics like throughput, end-to-end delay, packet delivery ratio, and energy efficiency.

Sarkar assessed AODV, OLSR, DYMO (dynamic MANET on-demand routing protocol), and BATMAN in heterogeneous MANET mobility contexts using OMNeT++. The findings indicated that high mobility can detrimentally affect AODV performance because high mobility caused links between nodes to fail frequently. Nonetheless, it should be noted that the study did not compare the various mobility models used or examine energy and routing overhead [5].

Kour and Ubhi examined how the nature of the terrain and mobility models affect the performance of AODV, DSR and OLSR. They reported that random waypoint performs best in open terrains and that structured mobility can enhance routing stability. However, energy consumption was not evaluated [6].

Pushpender Sarao performed AODV routing protocol with various random waypoint mobility model and random direction mobility models, emphasizing energy consumption and QoS constraints using NS2 as the testbed. They found that structured mobility provides a higher packet delivery ratio (PDR) and less packet loss but it is limited to a small network size study with no performance comparison against a static route (one without mobility) [7].

Arebi presented a multi-objective mechanism to optimize the AODV protocol through broken link repair and link lifetime optimization in a MANET. While the work investigates link repair and overhead at high mobility, it does not examine whether different mobility models or AODV speed scenarios were systematically included as comparisons to their modified AODV [8].

Using OMNeT++, Selim *et al*. compared eight MANET routing protocols (even AODV) using random waypoint mobility with variable node densities across multiple metrics including throughput, delay, energy consumption, jitter, packet loss, and PDR. The work serves as a wide-scope benchmark, but lacks variability of mobility model (only random waypoint) and a direct comparison between AODV and mobility model [9].

Abbas *et al*. examined the joint impact five mobility models (correlated direction, cauchy flight, exponential, levy flight, individual mobility) on routing protocol performance within OMNeT++. This study encompasses deployment & mobility complexity; however, it does not focus on AODV or trade-offs of energy/performance in IoT based studies [10].

Sirmollo and Bitew developed a mobility-aware routing algorithm (MARA) that improves the performance of MANETs by taking into account node speed, direction, distance, and remaining energy in its route determination process. Results from NS-2 simulations suggest that MARA provides better packet delivery, delay, and throughput than AODV. One limitation of the work is its reliance on GPS-based 2D single-mobility. The work has not been tested within a larger or mixed use scenario [11].

Daniel Gurvin Das and others. explored the impact of node mobility on reinforcement learning-based opportunistic routing protocols using mobility scenarios generated through BonMotion and simulated in NS-3 (Network Simulator-3). The analysis highlights the important role of mobility dimension and scenario tuning to achieve realistic MANET simulations. However, the study's focus on simulation-based validation limits the generalization to real dynamic environments [12].

Sahu and Mishra compared the performance of several mobility models: random walk, random direction, random waypoint, constant position, and Gauss-Markov. They used AODV, DSDV (Destination-Sequenced Distance Vector Routing Protocol) and OLSR routing protocols, simulating them in NS-3.22. in terms of packet delivery ratio, throughput, and packet loss with node densities from 10 to 50. The results showed that the Gauss-Markov mobility model performed better, especially with 50 nodes. However, in this case, the limitations were confined to a small area (50×50), and growth or energy had not been taken into account [13].

Three common limitations are identified from literature reviewed. First, the majority of studies consider only a single mobility model or a single traffic type (Das 2006b), which does not help to provide comprehensive insight on how mobility and QoS metrics relate with each other (Sarkar *et al*. 2025 [5]; Selim *et al*. 2025 [9]). Secondly, energy usage and routing overhead are seldom studied jointly although mobility has a direct impact on the number of route discovery attempts and control traffic. Third, another issue is that several existing papers assume a static/ homogeneous traffic model (i.e., use of CBR/FTP), whereas in say IoT based MANETs, we will have many applications. These gaps provide the motivation for our experimental setup: three mobility models compared in two speed conditions, with 30 applications and looking at energy as well as overhead. Our work provides a more comprehensive performance evaluation of MANET compared with earlier work by taking into consideration, mobility + speed + routing behavior + traffic heterogeneity together.

Although their study considers heterogeneity across nodes, they do not directly compare the effect of different mobility models (i.e., random walk vs. random waypoint) utilizing NetSim. We closely investigate AODV under multiple mobility models at varied velocities using NetSim v14.2 addressing this gap.

The improvement of our study over the previous studies are:

- Comparison of dual-mobility + dual-velocity performance (most analyses only employed a single mobility), past studies (for instance, Sarkar *et al*. 2025 [5]; Selim *et al*. 2025 [9]) evaluated mobility under a single mobility model (mainly random waypoint). Your study compares three models (no mobility, random walk, random waypoint) across two different speeds (10 m/s and 50 m/s), thus offering a more thorough analysis of the effects of mobility.
- Employs NetSim v14.2 to examine energy + routing overhead together: Almost all of the papers are using NS2, NS3, Omnet++, which are manual scripting and do not perform energy consumption, or overhead routing estimation. Our proposed research uses NetSim v14.2 because the NetSim simulator is able to calculate throughput, delay, PDR and energy consumption and implemented AODV and other routing protocols which are compliant with IEEE protocols, and realistic

mobility models.

- First to examine AODV in the disparate IoT-like traffic (30 applications): Most studies only run 1 or 2 types of traffic (CBR/FTP/HTTP). The proposed approach uses 30 mixed applications (email, HTTP, FTP, database, video, audio) that are closer to the actual IoT/smart city environment which makes the study more practical and relevant for real-world MANET-IoT systems.
- Performance of energy and mobility together: Includes energy consumption and routing overhead in addition to throughput, delay, and PDR. There are not many published studies that analyzed both mobility effects and energy usage as a function of different speeds. This paper demonstrated how increased mobility: Causes routing overhead → additional flooding of more control packets, causes energy consumption → due to more frequent route repairs so this dual analysis as research will lead to recommendations for battery-powered/mobility devices in IoT system (e.g., drones, sensors, rescue teams, military radios, etc.).

III. Theoretical Concepts

A. MANET-IoT

MANETs are networks that do not have any infrastructure. On networks without a fixed access point, each node can operate as a router. All nodes are free to move about and can be dynamically connected to one another in whatever way they want. Nodes collaboratively manage and organize the network. The entire network is mobile, and each terminal can move around freely. Due to frequent topology changes, several issues and challenges arise in MANETs. Key research areas include routing, energy efficiency, multicasting, clustering, and mobility management. In MANET, each node self-configures and acts as a router [3, 14]. 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 [10]. The IoT era has recently begun due to the explosive growth of IoT applications across numerous disciplines. The underlying Internet architecture has made it feasible for smart devices, apps, platforms, infrastructure, and human interactions to integrate into IoT systems. A key component of the IoT is device-to-device (D2D) communication, which enables direct connections between IoT devices without relying on existing facilities like access points or base stations. A MANET is a technology consisting of mobile nodes without a centralized administrator. MANETs are constructed from a connected array of IoT devices through D2D communication. MANET-assisted IoT architectures are developed by integrating MANETs with IoT technology, providing unprecedented capabilities [15, 16].

The interaction between MANET and IoT opens new ways for service provision in smart environments and challenging issues in its networking aspects. A key factor in MANET–IoT systems is energy balancing among nodes, since the IoT system is based mostly on many different wireless sensors and selection from MANET protocols focuses on the most efficient and shortest routes. The relationship between MANET and IoT creates new opportunities for system management arrangements in complex settings and testing problems [17]. The MANET-IoT concept is shown in Fig. 1.

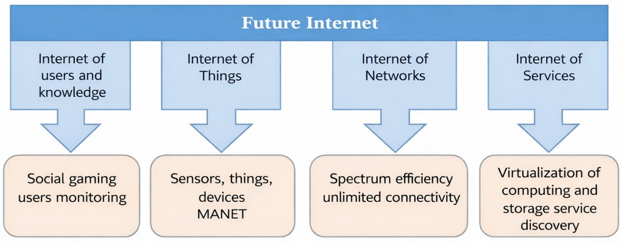


Fig. 1. MANET-IoT internet concept [18].

B. Routing Protocols

Two IoT devices may interact with each other, analogous to the data transmission among MANET nodes. Consequently, routing capacity is essential for the effective transmission of end-to-end data transfer, ensuring the reliability of the connection for remote data monitoring. Numerous studies undertaken in the previous decade evaluated several protocols to ascertain the optimal method for data transport. Routing protocols may be used inside an IoT MANET framework [19].

Classifications of manet routing protocols: Due to node mobility issue (Nodes constantly changing position) in MANETs, efficient routing protocols is needed for effective communication in MANETs. MANET routing protocols [20]. MANET routing protocols are classified according to Topology-based routing to:

Proactive routing protocol is table driven routing systems that maintaining a database of routing tables reflecting current network paths [20, 21]. Examples are DSDV, OLSR [22].

Reactive routing protocol is an on-demand routing technology for MANETs that utilizes bandwidth efficiently. When a source node intends to transmit data packets to a destination node using this protocol, the sender node initiates the route search process [20]. Examples are AODV and DSR [17].

Hybrid Routing Protocol utilizes both table-driven and demand-driven methodologies to enhance performance by integrating elements from reactive and proactive routing protocols [19]. An example is GRP (geographic routing protocol) [20].

Nodes in MANETs change position quite frequently, and this has a great impact on the performance of the routing algorithm. To reduce this problem, the node's mobility should be considered when designing a routing protocol for MANETs. The knowledge of the position is significant for successful routing of packets [23].

IV. RESEARCH METHOD

Network performance relies on the capacity of mobile nodes to process data packet and deliver it to the right destination at lower cost. Since nodes are free to move toward random destination, data delivery from a source to a destination might be disturbed due to frequent topology changes. Hence, mobility in mobile ad hoc network represents the main issue that should be addressed carefully while designing routing protocols [23].

A. Mobility Models

Mobility of node is a vital factor in the development of a stable route, scalable, and reliable routing protocol on ad hoc networks. Therefore, it has a major influence on overall network performance and should taken into consideration while studying such networks [24]. As nodes move arbitrarily, the network topology changes frequently, leading to link breakages, route rediscovery, and increased control overhead**.** Higher degrees of mobility often lead to increased packet loss, longer end-to-end delay, and lower throughput due to the instability in routes and the associated routing updates. Low mobility, or moderate mobility, improves connectivity and stability which increases the packet delivery ratio and reliability of the network. Therefore, in order to maintain quality of service and optimize performance, there needs to be an emphasis on the design of mobility-aware routing protocols for MANET applications [25].

1) Topology changes: The mobility of the nodes throughout the network increases the frequency with which communication links are established and broken. As such, the topology is dynamic, requiring constant routes to be discovered and routes maintained, resulting in increased routing overhead and control packet traffic.
2) Link breakage and packet loss: This high mobility may also result in an unstable link, leading to broken routes, delayed packet transmission, and an increased packet loss ratio. Occasionally, routing protocols will need to update routes, which is costly in terms of bandwidth and battery.
3) End-to-end delay: The dynamicity of the network means that when a route breaks, a packet may be buffered or retransmitted, resulting in a higher end-to-end delay. In a reactive protocol such as AODV or DSR, even further delays may be required to re-establish the route.
4) Throughput reduction: A node's speed will mean that if links are broken frequently, throughput will decrease as packets will be dropped and delivery is intermittent. However, moderately mobile nodes may improve throughput due to increased routing options and connectivity of nodes throughout the network. Routing overhead and energy consumption: the need for constant route updates in high-mobility environments generates extra control messages, raising routing overhead and energy consumption—critical concerns for battery-powered mobile nodes.
5) Impact on QoS: Overall, node mobility affects all QoS parameters—latency, Packet Delivery Ratio (PDR), throughput, and reliability—making it essential to design routing protocols that can adapt quickly to mobility-induced topology variations.

MANET nodes do not have a fixed location, which means that they are moving from one place to another at varying speeds. The speed of nodes affects the result of the simulation [17].

The purpose of this paper is to study the impact of node mobility on the performance of well-known routing protocols such as Ad-Hoc on Demand Distance Vector (AODV). We assessed the efficiency of each protocol under high mobility environment. Performance assessment is based on the conventional metrics such as latency, throughput, Packet Delivery Ratio (PDR), routing overhead energy consumption. This study in number of NetSim v14.2 simulation program which was selected for MANET simulation because it provides a comprehensive, IEEE-compliant environment for modeling mobile and wireless networks with built-in support for key protocols such as AODV, DSR, and OLSR. It offers realistic mobility models, automatic calculation of QoS metrics (throughput, delay, PDR, routing overhead, and energy consumption), and an interactive GUI for visual analysis. Compared with tools like NS2 or NS3.

The three mobility models (no mobility, random walk and random waypoint) are chosen as they are the three basic and most widely implemented movement models in MANET simulation research. On the one hand, the No-mobility model offers a steady-state baseline by which node mobility can be compared against and contrasted with deterministic IoT network deployments where devices are stationary. Second, the Random Walk model also captures strongly unpredictable, unstructured mobility and is commonly used to evaluate worst-case dynamic topologies. And the most used model in simulations of MANET and IoT is Random Waypoint model, as it tries to mimic the human movement opportunity with move pause time at intervals along with destination driven mobility. Together, all these three models span the complete range from stationary over arbitrarily moving to managed mobility for a thorough analysis under AODV.

NetSim enables easier experiment configuration, visualization, and accurate performance evaluation of dynamic MANET simulation scenarios with different type of mobility models as follows:

B. Simulation Steps

The simulations were performed in an area of size 1000×10001000 \times 10001000×1000 m which can be considered a medium scale MANET/IoT deployment. Both scenarios were performed for the duration of 100 s of simulation time. The transmission range of the nodes is 250 m, equal to IEEE-802. 11g radio configuration in NetSim. An overall of 30 application flows were produced, which consisted of FTP, HTTP, Email, Video and Voice streams with CBR-based and TCP traffic bandwidth (size of packets equal to 512 bytes in the case of CBR flows;1500 bytes concerning video packets). The MAC protocol was IEEE-802. 11, and Two-Ray-Ground model served for the propagation model. Pause time was

2 s for the random waypoint model and no pause for random walk. Mobility speeds were set to 10 m/s and 50 m/s, representing a realistic MANET-IoT communication setup: different application requirements are evaluated under diverse mobility patterns.

30 flows were chosen to simulate a real IoT/MANET scenario, where numerous services (Email, HTTP, File Transfer, Database, Audio and Video) coexist. With a large number of simultaneous flows, the routing protocol is tested under mild congestion and multi service routing request pressure. Meanwhile 30 flows are not too intensive to oversaturate the topology, and therefore we can differentiate the effect of mobility on AODV performance, without burdening the network with load experienced packet loss. Thus, the selected traffic load represents a compromise between realism and experimental controllability.

A network of 10 nodes shown in Fig. 2 moving at a velocity of 10 m/s, with the traffic load incrementally increased up to a total of 30 applications with different mobility models to examine the performance of each model with AODV routing protocols.

Scenario 1: No mobility: In this scenario, the performance of the AODV protocol was analyzed when the node is stationary; it does not move during the simulation. Use this when you want fixed IoT devices (e.g., sensors, routers, base stations).

Scenario 2: Random walk: in this scenario, the node moves in *random directions* with random speeds. After each interval, the node randomly selects a new direction and continues. Useful for simple dynamic networks or to test unpredictable movement.

Scenario 3: Random waypoint: in this scenario, the node randomly selects a destination within the simulation area and moves there at a chosen speed. After reaching, it may pause for some time and choose another destination. This is the most common model used for MANETs and IoT mobility studies.

These three scenarios are applied with AODV routing protocol with the 10 m/s velocity and the QoS parameters (throughput, delay, packet delay ratio, routing overhead and energy consumption are measured to examine which model is better in terms of these QoS parameters.

Other three scenarios are applied with AODV routing protocol but the velocity had increased to 50 m/s and the QoS parameters (throughput, delay, packet delay ratio, routing overhead and energy consumption are measured to examine which model is better in terms of these QoS parameters.

All the scenarios had been run with simulation time (100 sec) and the results had been shown in the following section.

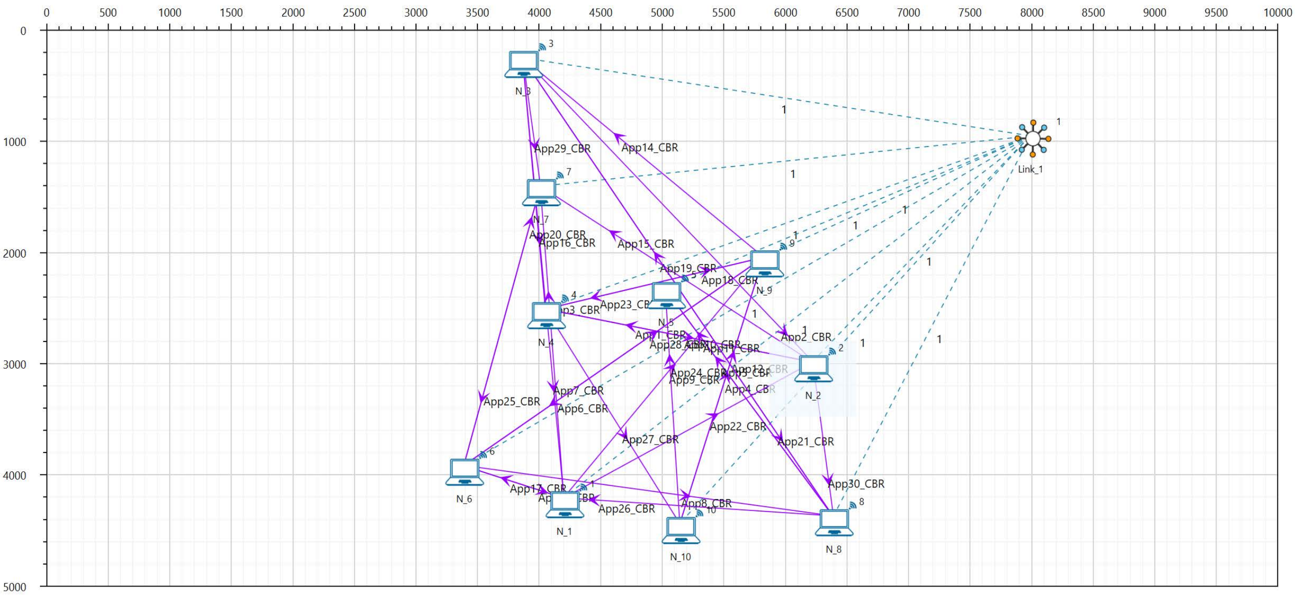


Fig. 2. MANET topology.

Note that the number of randomly selected nodes in this study is 10, because it is a typical scale of MANET-IoT deployments used to evaluate mobility behaviors and enables to separate mobility behavior without experiencing congesting based routing failure concurrently. By creating redundant paths, a larger number of nodes can hide mobility-induced degradation. At 10 nodes the separate effect of mobility on AODV route establishment, control overhead and energy consumption is more pronounced. Indefinitely A simulation time of 100 seconds, similarly the choice of a 100 second simulation with no error is common in MANET literature gives enough time for node mobility to trigger multiple route[s] re-establishment[s] and topology change[s], without simulating too short a period which could induce artifacts related to convergence/dispersion effects. Therefore, the chosen parameters result in a managed microcosm that is capable of capturing mobility's effect on AODV.

V. Result and Discussion

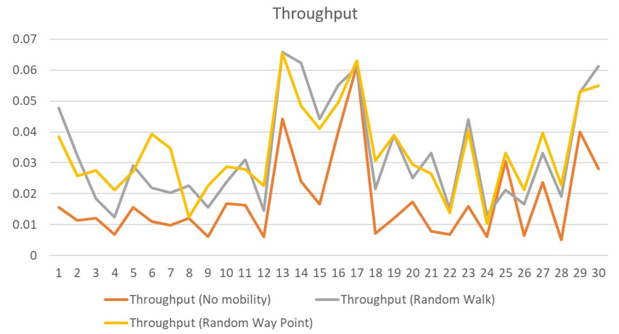
The performance of the AODV routing protocol was evaluated under three distinct mobility scenarios—no mobility, random walk, and random waypoint—each simulated with 30 heterogeneous application flows (Email, HTTP, File Transfer, Database, Audio, and Video). The node velocity was fixed at 10 m/s for the mobile scenarios, while in the static (no mobility) case, nodes remained stationary throughout the simulation. The following subsections discuss the impact of these mobility models on the five key QoS performance metrics.

Throughput, delay, packet delay ratio, routing overhead and energy consumption had been examined between no mobility compared with two mobility models (random walk and random way point) and the velocity is 10 m/s as shown in Fig. 3. Throughput reflects the average successful data transmission rate in the network.

Results show that the no-mobility scenario achieved the lowest throughput, averaging around 0.011 Mbps, compared to 0.017 Mbps to 0.022 Mbps under random walk and random waypoint mobility models. This behavior arises because, in static topologies, routes remain fixed but often become suboptimal due to limited link diversity. In contrast, node movement in random walk and random waypoint models creates more dynamic link opportunities, improving the probability of successful packet forwarding and route availability. However, among the two mobility models, random waypoint consistently yielded slightly higher throughput than random walk. It is due to the break time in random waypoint which lowered occurrences of link disruption, while providing a chance to maintain more stable routes supporting sustained data flow.

The overall end-to-end delay resulted from the node mobility pattern. In the no-mobility scenario, the packets experienced long queueing and processing delays because both routing paths and congestion were pre-determined. Once mobility came into play, there was a noticeable decrease in average delay due to the protocol's abilities to dynamically discover alternate, shorter paths, most especially with random waypoint. The lowest average time delay was with random waypoint. However, due to nodes moving through space at random without pauses, random walk nodes experienced brief spikes as they became disconnected from their routing path. The random waypoint nodes operated the smoothest overall with less delay as nodes frequently paused for updated route information. Based on a reasonable, moderate mobility experience, there was better delay performance observed with AODV routing using the random waypoint model. In sum, moderate, structured mobility yielded a lower latency for AODV performance.

The PDR noticeably increased with mobility. In the static scenario, the PDR averaged about 52.8 %. Under a random walk movement, the PDR improved slightly to about 63 %, and increased again to 71 % in the random waypoint model. The static scenario produced lower PDR because the paths for the links remained consistent even though congestion was being experienced; since the AODV cannot find alternate paths around overly congested nodes, the overall delivery efficiency directly correlated to decreased area congestion normalizes the algorithm. On the other hand, with mobility of nodes route variability allowed more packets overall to reach their destination through newly formed links. When comparing mobility, random waypoint consistently proves to have the highest PDR since the mobility of its nodes helps to create some stability in the packet's path to its destination, where packets are dropped from these paths was less than other mobility models due to path breaks. Therefore, with controlled mobility of nodes with proper path management in these highly mobile situations the efficiency of packet delivery increases, proving that even in a highly mobile network such as MANET can still produce a desirable outcome.



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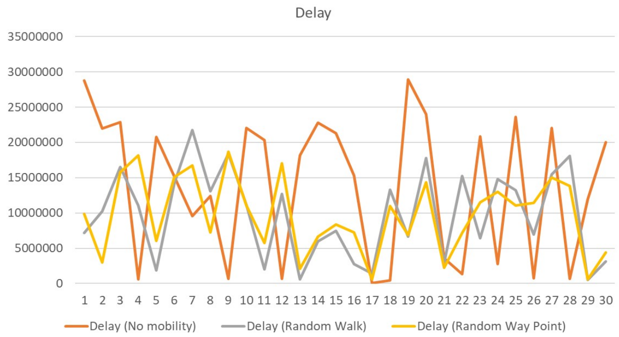

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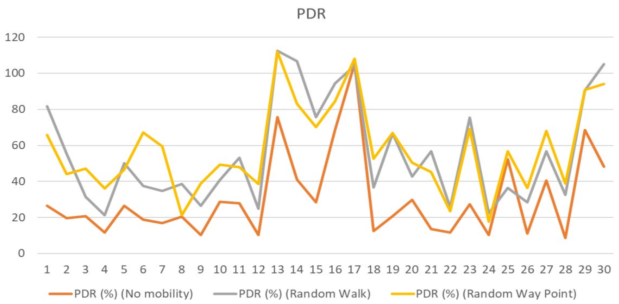

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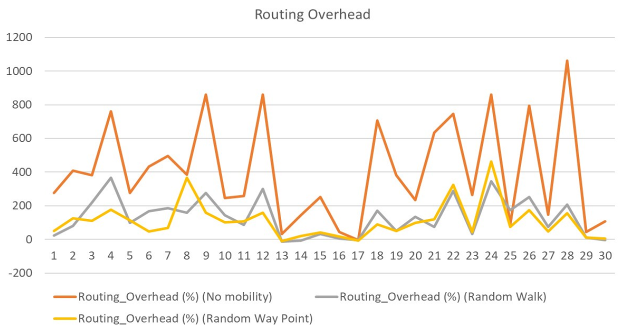

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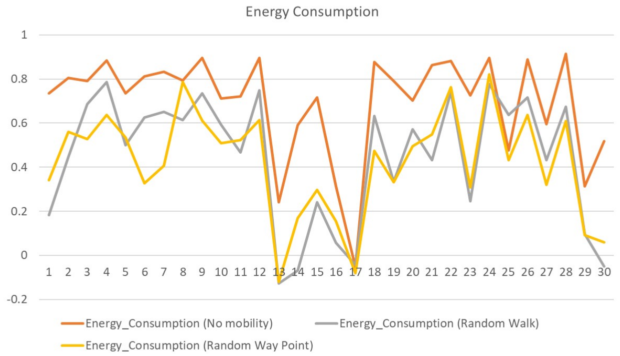


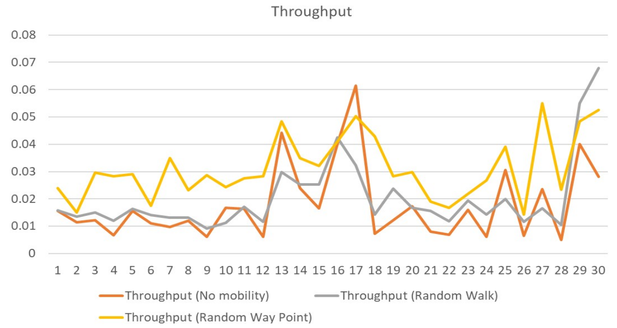
(e)

Fig. 3. Performance of AODV under 10 m/s for all mobility models: (a) Throughput, (b) delay, (c) PDR, (d) routing overhead, (e) energy consumption.

As we predicted, routing overhead increased with mobility. In the no-mobility case, the overhead remained quite low, as the routes were established once and reused across the simulation. In the case of random walk, the overhead increased dramatically because of the frequent discovery of routes as a result of the random walking of nodes. Every link break involving a node triggered additional RREQ and RREP messages, consuming bandwidth and raising signaling overhead. random waypoint, although still mobile, created slightly lower overhead than random walk, due to its pause times reducing the frequency of route rediscovery. Overall, random walk presented the maximum routing overhead, indicating the trade-off between frequent route adaption and control message overhead, demonstrated in reactive protocols, such as AODV.

Energy consumption showed a striking similarity to routing overhead. When there was no mobility, energy consumption was modest because very few control messages were sent. In random walk, there was a high frequency of route changes and, hence, too many exchanges of control packets, retransmissions, and attempts to re-establish connections, which led to excessive power usage. Meanwhile, random waypoint was a more energy efficient behavior than random walk; the way nodes moved allowed them to idly wait for a short period of time, thus leading to less transmission activity in total. Ultimately, random waypoint mobility offered the most balanced performance, yielding high throughput, and Packet Delivery Rate (PDR), moderate delay, and energy consumption. However, with random walk's mobility is dynamic, there was an unwillingness to stabilize the routing behavior and without this, unpredictable overhead was introduced and energy wasted. The no mobility scenario was energy efficient but penalized the routing performance through route stasis, congestion, and poor PDR. Thus, AODV being an adaptive routing protocol is well suited to take advantage of moderate structured mobility, demonstrating that controlled movement would produce a better routing outcome for the MANET than no mobility or highly random behavior.

For 10 m/s, the best throughput was obtained by random waypoint, 0.022 Mbps (100% increase compared to static, that reached 0.011Mbps) and higher than random walk in 29% (that got a throughput of 0.017 Mbps). Regarding PDR, the static case could achieve 52.8% as opposed to 63% for random walk and to 71% for random waypoint which are an enhancement of 18% and 34% respectively. It also reduces the delay by about 19-27% under random waypoint as compared with static and random walk. At the moderate mobilities, these numberical results indicate the mobility is effective on the expanding of available routing paths and in enhancing packet forwarding under AODV.



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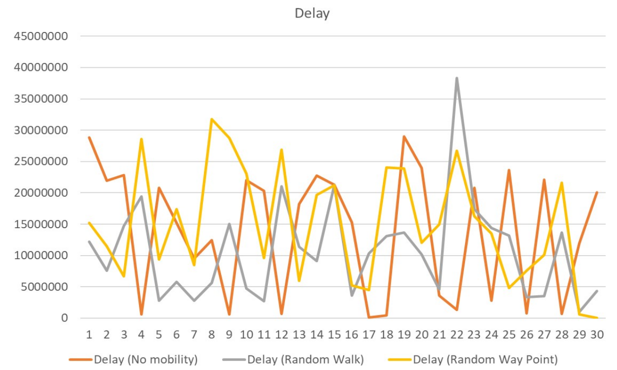

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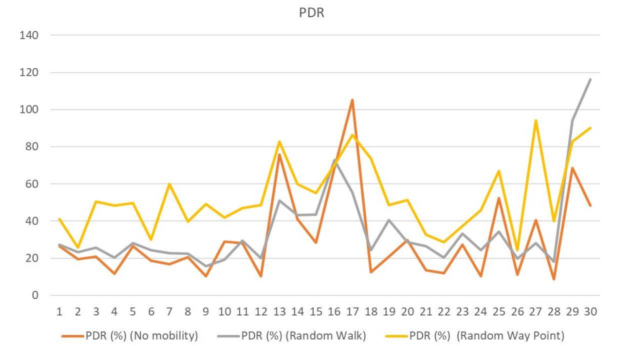

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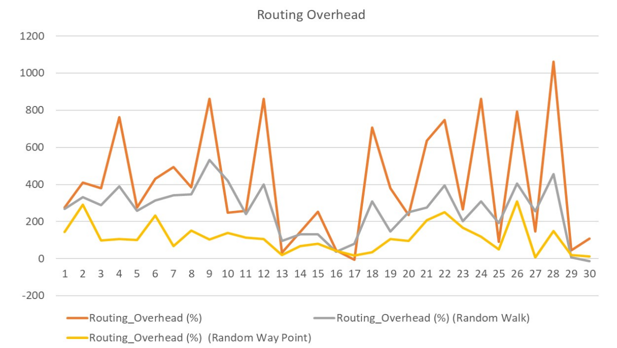

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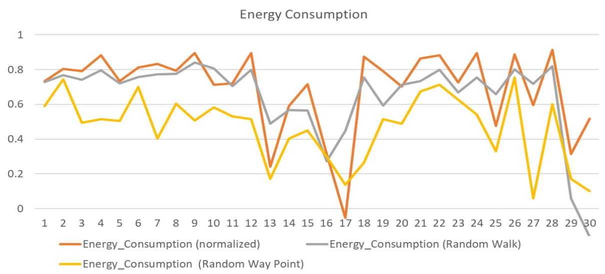

(e)

Fig. 4. Performance of AODV under 50 m/s for all mobility models: (a) Throughput, (b) delay, (c) PDR, (d) routing overhead, (e) energy consumption.

The performance of the AODV routing protocol was evaluated in three different mobility scenarios: No mobility, random walk, and random waypoint; and a fixed node velocity of 50 m/s. The purpose of this was to analyze the node's mobility intensity and mobility pattern on network performance on five QoS parameters of throughput, delay, Packet Delivery Ratio (PDR), Routing Overhead (RO), and Energy Consumption (EC). These are displayed in Fig. 4.

At this 50 m/s velocity, the throughput decreased for all models due to more frequent link breaks, resulting in reduced stable periods for transmission. The no-mobility case produced the lowest throughput; however, the random waypoint slightly outperformed the random walk because it had pause times which provided brief periods of route stabilization. Regardless of the model selected, throughput declined approximately 15–25 % in comparison to 10m/s.

The higher node velocity resulted in increased average end-to-end delay, primarily because the nodes repeatedly discovered routes. random waypoint again achieved the least delay, although all scenarios showed a clear increase in latency compared to the lower-speed case, reinforcing that the intensity of mobility significantly influences routing responsiveness.

At a speed of 50 m/s, PDR decreased significantly for both mobility models.

Although random waypoint still ensured higher delivery (≈ 65 %) than random walk (≈ 58 %), overall reliability was reduced by nearly 10% damning compared to 10m/s.

The dropped reliability is largely due to the higher rate of route failures and packet losses at higher speeds.

Routing overhead increased significantly as mobility increased.

The instances of link disconnection forced AODV to send RREQ/RREP messages with high frequency, especially under random walk where random motion led to excessive rediscovery. Under random waypoint, while fewer control packets were used due to the controlled movement, routing protocols still used more bandwidth than a static case.

Energy consumption paralleled routing overhead. At 50 m/s, nodes used more energy to sustain routes and retransmit packets dropped by the transport and application layers. random walk exhibited higher energy consumption while random waypoint was moderately less energy-consuming amid its intermittent pauses. Overall, we can conclude that increasing the speed of the nodes from 10 m/s to 50 m/s has a negative impact on AODV performance with more packets lost, higher delay, and more control overhead. Despite the decline in performance, random waypoint mobility was still the most stable and energy-efficient model across both speeds. Random walk had the highest fluctuation and control overhead, whereas Node Mobility continually had low throughput and PDR due to the nature of the mobility model within the context of mostly static paths.

At higher speed (50 m/s), throughput for all the models was 15–25% lower than at 10 m/s, which is due to the time varying topology effect. PDR 58% under random walk, and 65% for random waypoint to an approximately 10 % decrease from the lower speed movement. Routing overhead and energy consumption increased over 27–39% due to the frequent rate of route failure and retransmissons.

The static case obtained the worst result because it had the lowest throughput (0.011 Mbps) and PDR (52.8%). AODV is unable to make use of alternate routes when a congested or suboptimal path occurs with static nodes. As the routes are fixed, any interference or over-loaded link becomes a bottleneck leading to reduced PDR and throughput.

It is apparent that random waypoint outperforms the static case by at most 100 % of throughput and 34% of PDR, and also beats random walk by at most 29 % of throughput, indicating its better practicality to realistic MANET-IoT environments.

VI. Conclusions

This study examined the impacts of varied mobility models on the AODV routing protocol performance in MANET settings through the application of NetSim v14.2. This simulation platform was chosen because of its ability to accurately model network layers compliant with IEEE guidelines, its support for realistic mobility patterns, and its automated metrics for QoS parameters, making it ideal for comparing behaviors in dynamic routing scenarios without using real hardware. NetSim interfaces with a visual and user-friendly framework that makes validating and examining routing solutions in mobile and wireless scenarios easier than traditional tools like NS-2 and NS-3. The simulation results highlighted a clear effect of node mobility on MANET performance. When nodes were moving at a low-speed (10 m/s), the random waypoint model produced the best results, as it was able to achieve higher throughput, a better packet delivery ratio, and lower delay compared to both the random walk scenario and the No-Mobility scenario, while maintaining a suitable level of energy efficiency. When node velocity was relatively increased to 50 m/s, throughput and packet delivery ratio diminished, while routing overhead and energy per packet increased due to more frequent eviction of channel links and variation in topology. Despite this, it was evident that random waypoint performed the best within both the moderate-speed and high-speed mobility categories, which only added to its favorable performance attributes. In conclusion, the combination of structured mobility and adaptive routing (AODV) shows the best performance in MANETs with a good tradeoff of reliability, delay and energy efficiency. The results suggest that NetSim is well suited to accurately, and more broadly, assess the behavior of MANET and IoT-based networks. Although, the results showed that structured mobility leads to routing stability and less packet loss in AODV-based MANETs, the findings are however confined due to the size of our network (10 nodes) as well synthetic mobility, as well as a single routing protocol. An ideal wireless medium is assumed during study with IEEE-802. 11 MAC and is still without real-world challenges, interference, or node failure. These restrictions does not affect the relative trends but they bind direct general considerations to more extensive IoT deployments. In the future, this work can be expended by scaling up the MANET and applying heterogeneous node densities as well as proving of our claims through real mobility traces. Another direction is to contrast AODV with hybrid and energy- aware routes protocols, by taking more realistic environments into account, e.g. shadowing, interference and energy harvesting nodes. Finally, real experiments or test-bed verification would support simulation results and increase external validity of the findings. As a future work, we intend to include different traffic load scenarios in the network to study the joint effect of mobility and network congestion.

Conflict of Interest

The authors declare no conflict of interest.

Author Contributions

Shayma Wail and Yousra Mohammed conducted the research; Shayma Wail and Nadia I. analyzed the data; Shayma Wail wrote the paper; all authors had approved the final version.

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