EURASIAN PHYSICAL TECHNICAL JOURNAL

202X, Volume 21, No. 2 (48)

https://doi.org/10.31489/2024No2/70-82

Received: 31/01/2024 Revised: 13/05/2024 Accepted: 18/06/2024 Published online: 29/06/2024

Original Research Article

UDC 53.072

EVALUATING ROUTING ALGORITHMS ACROSS DIFFERENT WIRELESS MESH NETWORK TOPOLOGIES USING NS-3 SIMULATOR

Turlykozhayeva D.A. *, Akhtanov S.N., Baigaliyeva A.N., Temesheva S.A., Zhexebay D.M., Zaidyn M., Ussipov N.M., Skabylov A. A.

al-Farabi Kazakh National University, Almaty, Kazakhstan
Corresponding author: turlykozhayeva.dana@kaznu.kz

Abstract. *Wireless Mesh Networks are gaining traction as a solution for delivering reliable connectivity without centralized infrastructure. They operate through wireless node interconnections, forming self-configuring networks ideal for scenarios where wired networks are impractical. Routing is crucial in Wireless Mesh Networks to ensure efficient communication among nodes. However, the suitability of routing algorithms for Wireless Mesh Network's topology requires further investigation. This paper proposes an investigation into the effectiveness of routing algorithms like AODV, DSDV, and OLSR across various Wireless Mesh Networks topologies using NS-3 simulation. It also aims to determine the optimal number of nodes and protocols to maximize throughput and minimize packet loss within a limited area. Through rigorous NS-3 simulations, the study demonstrates that AODV, DSDV, and OLSR exhibit differing effectiveness across random, mesh grid, and Fruchterman-Reingold topologies. These results emphasize the importance of considering topology-specific factors when selecting and optimizing routing protocols for Wireless Mesh Networks. In summary, Wireless Mesh Networks offer decentralized connectivity, but the effectiveness of routing algorithms in different topologies remains understudied. This investigation addresses this gap by evaluating routing algorithms across various topologies, shedding light on their suitability and performance in Wireless Mesh Networks.*

Keywords: Wireless Mesh Networks; Ad hoc On-Demand Distance Vector; Destination Sequenced Distance Vector; Optimized Link State Routing Protocol; Proactive Routing Protocols; NS-3.

1. Introduction

Wireless Mesh Networks (WMNs) have become a highly promising technology for providing robust and reliable connectivity in diverse environments, offering seamless coverage and efficient data transmission. This network type is distinguished by its self-organizing and self-configuring capabilities, requiring minimal initial investment for deployment. WMNs demonstrate versatile applicability by supporting a wide range of applications, including broadband home networks, education, healthcare, building automation, rescue operations, and military applications [1]. The architecture of a Wireless Mesh Network (WMN) is structured into three logically organized layers: Mesh Routers (MRs), Mesh Gateways (MGs), and Mesh Clients (MCs). Within this framework, Mesh Clients (MCs) encompass a variety of devices, including desktop computers, mobile devices, laptops, and Pocket-PCs, all establishing their connections to the internet through Mesh Routers (MRs). As intermediaries, Mesh Routers (MRs) are essential for transmitting network traffic to Mesh Gateways (MGs), which have direct connections to the internet infrastructure [2].

A crucial factor impacting WMN performance is the routing protocol used to forward data packets within the network. The dynamic and constantly shifting topology of client nodes significantly challenges the routing processes in WMNs. Effective data routing plays a key role in ensuring reliable communication between nodes, considering the specific features of the network topology. Despite the variety of routing algorithms available, their applicability in WMN topologies remains an under-researched area [3].

This article presents a study that assesses the performance of routing algorithms across various WMN topologies, using simulations conducted with the NS-3 modeling environment. Specifically, three routing protocols are evaluated: Ad hoc On-Demand Distance Vector (AODV), Destination Sequenced Distance Vector (DSDV), and Optimized Link State Routing Protocol (OLSR). To assess the effectiveness of these routing algorithms, a set of key routing metrics is considered, including throughput, jitter, time delay, and packet loss. These metrics play a crucial role for assessing the performance of routing protocols in WMN topologies. Additionally, this research aims to ascertain the optimal combination of nodes and protocols within a limited 1x1 km square area to achieve maximum throughput and minimize packet loss. The latest versions of routing protocols within NS-3.40 were utilized for this research.

The article is organized into five sections. Section II highlights related work on routing protocols, while Section III provides an overview of the selected routing protocols designed for WMNs, laying the groundwork for the comparative analysis presented in this study. Section IV is dedicated to different wireless mesh network topologies, such as random, mesh grid, and Fruchterman-Reingold. Section V showcases and discusses results, offering insights and interpretations based on the evaluation. Finally, a conclusion is presented to succinctly summarize the key features and findings of our study.

2. Related works

Rajeev Paulus and colleagues [4] conducted a comparison of the Ad hoc On-Demand Distance Vector (AODV), DSR, OLSR, and ZRP routing protocols. They utilized QualNet version 6.1 to evaluate the performance of these protocols based on metrics such as throughput, packet delivery ratio (PDR), average end-to-end delay, and average jitter. The findings indicated that ZRP exhibited slower speeds and lower packet delivery success rates compared to other protocols, particularly when encountering changes in pause time and maximum speed. AODV demonstrated superior performance across all criteria. While DSR outperformed OLSR and ZRP in terms of speed and packet delivery success, it exhibited the poorest performance in terms of average jitter and delay. OLSR exhibited the least favorable results for average jitter and delay, especially when pause times varied. These conclusions offer valuable insights for selecting the most suitable method when designing and utilizing computer networks.

Samba Sesay and colleagues [5] conducted a survey that examined the performance of DSDV, DSR, TORA, and AODV using an extended version of the UCB/LBNL network simulator ns-2. The simulation encompassed a virtual environment measuring 1200 by 300 meters and lasted 600 seconds. The study focused on several metrics, including throughput, average end-to-end latency, packet delivery ratio, route acquisition time, and routing overhead. Notably, DSR demonstrated superior performance with lower routing overhead across all scenarios. Conversely, DSDV showed suboptimal performance, particularly under conditions of high movement speeds and node density. TORA exhibited excellent performance, especially in larger networks characterized by high mobility rates and movement speeds. These findings offer valuable insights into the comparative strengths and weaknesses of these routing protocols in simulated settings.

Charles E. Perkins and colleagues [6] examined the performance of two prominent on-demand routing protocols, DSR and AODV, in ad hoc networks. Using the Ns-2 network simulator, the study evaluated various characteristics, including normalized routing load, normalized MAC load (reflecting efficient wireless medium utilization by data traffic), average end-to-end delay, and packet delivery ratio. The analysis revealed that DSR exhibited inadequate latency and throughput performance, primarily attributed to its aggressive caching technique and the absence of mechanisms for managing older routes or ensuring route freshness in scenarios with multiple choices. These findings contribute to the academic understanding of on-demand routing protocols in ad hoc networks [6].

Josh Broch and colleagues [7] investigated the performances of DSDV, TORA, DSR, and AODV using the ns network simulator. The study entailed comparing parameters such as packet delivery, routing overhead, path optimality, and node movement speed. Despite TORA being identified as the poorest performer in terms of routing packet overhead, it still succeeded in delivering over 90% of packets in scenarios with 10 or 20 sources. AODV demonstrated nearly equivalent performance to DSR across various mobility rates and movement speeds, effectively achieving its goal of eliminating source routing overhead.

3. Routing protocols

The primary aim of routing in wireless mesh networks (WMNs) is to establish efficient paths for transmitting data packets between source and destination nodes within the network. Routing protocols in WMNs can be broadly categorized into three types: proactive, reactive, and hybrid, based on their approach to packet forwarding [8]. Proactive routing protocols, also known as table-driven methods, establish paths to all accessible destination nodes, regardless of whether they are currently required for data transmission. These protocols continuously compute routes to all reachable nodes, providing consistent and up-to-date routing information. The main advantage of proactive protocols lies in nodes quickly acquiring routing information, enabling rapid pathway establishment [9].

Reactive routing protocols, or on-demand methods, establish routes only when necessary. When a source node needs a route to a destination node, the route discovery process is initiated. This process continues until a route is found or until all potential routes are explored without success. In WMNs with minimal node mobility, reactive routing protocols offer superior scalability despite potential disruptions to active routes due to node mobility in mobile networks [10]. Hybrid Routing Protocols combine the strengths of proactive and reactive routing protocols while mitigating their weaknesses to identify optimal routes with minimal management overhead. This protocol type employs different routing protocols in various segments of the WMN infrastructure. Reactive protocols are used in the ad hoc network area, while proactive protocols are implemented in the wireless backbone, ensuring efficient and adaptive routing [11].

This study provides a comprehensive overview of three routing protocols: AODV, DSDV, and OLSR.

The Ad hoc On-Demand Distance Vector (AODV) algorithm facilitates the creation of dynamic, self-initiating, multihop routes among mobile nodes within an ad hoc network, and operates reactively by establishing routes only when needed in response to specific communication requests. AODV enables swift acquisition of routes to new destinations without necessitating the maintenance of routes to inactive destinations. Furthermore, it enables mobile nodes to promptly adapt to changes in network topology and respond to link failures [12].

AODV operates without loops, steering clear of the "counting to infinity" issue associated with the Bellman-Ford algorithm. This ensures rapid convergence in the face of changes in ad hoc network topology, especially when nodes relocate. In cases of link failures, AODV promptly notifies the affected nodes, allowing them to invalidate routes associated with the disconnected links [13].

A standout aspect of AODV is how it employs destination sequence numbers for each route entry. The destination itself generates this sequence number, which gets shared with requesting nodes along with route details. This clever use of destination sequence numbers guarantees loop-free routing and is easy to implement. When faced with two route options to a destination, a requesting node must opt for the one with the highest sequence number [14].

The AODV routing protocol is tailored for mobile ad hoc networks encompassing populations ranging from tens to thousands of mobile nodes. It can adeptly handle varying mobility rates, spanning from low to moderate and even relatively high, accommodating diverse levels of data traffic. AODV is specifically crafted for networks where mutual trust among nodes is established, either through preconfigured keys or a confirmed absence of malicious intruders [15]. The design of AODV prioritizes minimizing control traffic dissemination and cutting down on data traffic overhead, aiming to enhance scalability and overall performance.

The DSDV (Destination-Sequenced Distance Vector) is a proactive protocol that employs the Bellman-Ford algorithm to compute optimal paths in mobile ad hoc networks (MANETs). Its choice of hop count as the cost metric reflects the number of hops a packet must traverse to reach its intended destination. Unlike reactive protocols, DSDV is proactive and maintains a comprehensive routing table encompassing all nodes within the network, not solely its immediate neighbors [16].

The protocol employs both periodic and trigger-based update mechanisms to disseminate routing information. However, the inherent nature of periodic updates introduces the potential for routing loops. To address this concern, DSDV introduces the concept of sequence numbers. Each node independently selects its sequence number, ensuring incremental values with each periodic update [17]. Notably, these sequence numbers are always even, a deliberate design choice that simplifies the protocol's operations.

When a node must send an update for a route that has expired to its neighboring nodes, it increases the sequence number of the disconnected node by 1. Receivers of these updates check the sequence number; if it's an odd value, they remove the related entry from the routing table, preventing routing loops.

In the dynamic environment of MANETs, where node mobility can lead to frequent route fluctuations, DSDV incorporates a settling time mechanism. This feature helps dampen the impact of rapid changes, contributing to the stability and reliability of the protocol in the face of evolving network topologies. Overall, DSDV strikes a balance between proactive route maintenance and effective loop prevention, making it a valuable contender in the realm of mobile ad hoc networking protocols [19-21].

The Optimized Link State Routing Protocol (OLSR) is specifically designed for mobile ad hoc networks, functioning as a proactive, table-driven protocol [22, 23]. It consistently exchanges topology information with other nodes in the network. Within OLSR, each node strategically selects a subset of its neighbors as "multipoint relays" (MPRs). These MPRs play a crucial role in forwarding control traffic, efficiently disseminating it throughout the network and minimizing required transmissions. MPR nodes carry a special responsibility in announcing link-state information within the network. OLSR ensures the shortest path routes to all destinations by mandating that MPR nodes declare link-state information for their selected MPRs. Any additional available link-state information can be utilized for redundancy purposes [24].

Nodes designated as MPRs periodically broadcast this status in their control messages, signaling their accessibility to nodes that have designated them as MPRs. In route calculation, MPRs are crucial in establishing routes from a given node to any destination in the network. They also facilitate efficient flooding of control messages across the network [25]. OLSR adopts a cautious approach in MPR selection, picking from one-hop neighbors with bidirectional, symmetric connections. This guarantees that the chosen route through MPRs avoids problems associated with data packet transfer over unidirectional links, such as the absence of link-layer acknowledgments for data packets at each hop, particularly in link-layer implementations utilizing unicast traffic [26].

4. Topologies

Topology in wireless networks refers to the physical or logical structure, organization, and distribution of nodes and connections. The topology defines how devices connect and communicate with each other within a WMN. There are various types of WMN topologies such as random, mesh grid, and Reingold, which we discussed further [27].

Random topology refers to the structural configuration or arrangement of elements within a system or network that lacks a specific pattern or predetermined organization. In different contexts such as network theory, graph theory, or complex systems analysis, a random topology suggests that the connections between components or nodes are formed based on a probabilistic or stochastic process, rather than being systematically arranged or structured according to a defined rule or pattern. For example, in a random network topology, nodes might relate to a certain probability, leading to a heterogeneous and often unpredictable network structure. This contrasts with regular or ordered topologies where connections follow specific rules or patterns, such as in a grid or lattice network. Random topology often exhibits properties such as high variability, robustness, and resilience to certain types of failures or attacks due to its lack of centralized organization [28]. Below, in Figure 1, a random network is constructed and subsequently utilized in the investigation of routing algorithms in Section V.

In wireless mesh networks, the mesh grid topology refers to a structured arrangement where network nodes are organized in a grid-like fashion. Each node typically communicates with its immediate neighbors, forming a dense mesh of interconnected nodes. Mesh grid topologies can be easily scaled by adding more nodes in a systematic grid pattern, allowing for efficient expansion of network coverage. The structured nature of the mesh grid topology enhances network reliability, as multiple redundant paths are available for data transmission. If one path fails, alternative routes can be quickly utilized, minimizing disruptions in communication. Due to the proximity of neighboring nodes, data transmission within a mesh grid network tends to have low latency, making it suitable for applications requiring real-time communication, such as video streaming or online gaming. The predictable arrangement of nodes in a mesh grid topology simplifies network planning and deployment. Nodes can be strategically positioned to optimize coverage and connectivity. Mesh grid topologies ensure uniform coverage across the network area, minimizing dead zones and ensuring consistent signal strength throughout the deployment area. However, mesh grid topologies often require a fixed infrastructure to support the grid layout, such as poles or buildings for node placement.

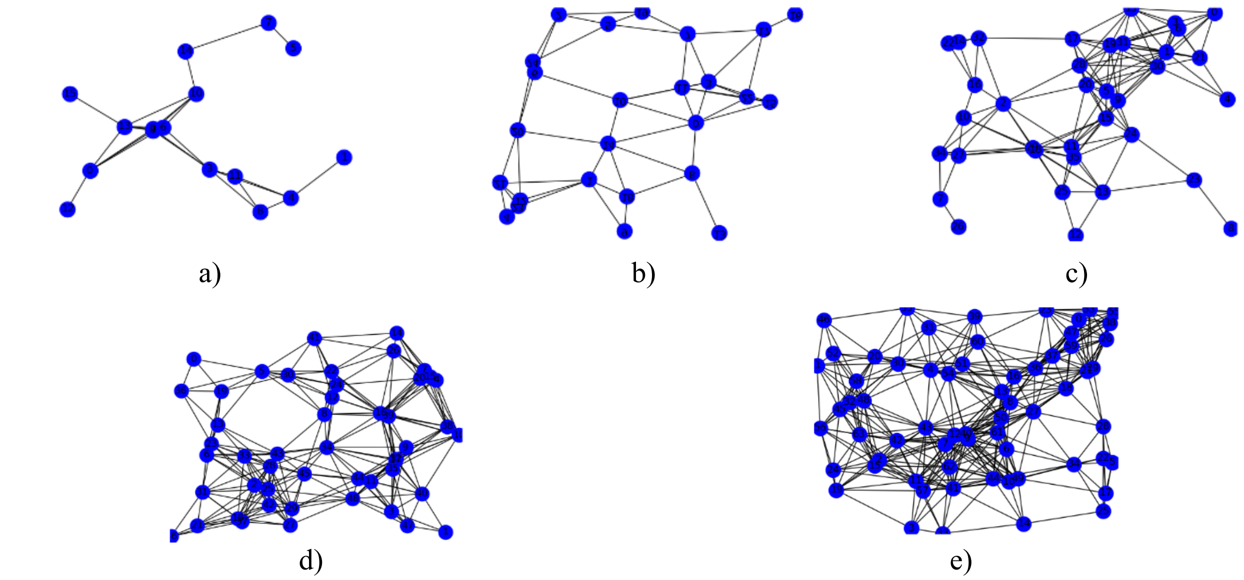

Fig.1. Random topology, where a) 4x4 (16 nodes); b) 5x5 (25 nodes); c) 6x6 (36 nodes); d) 7x7 (49 nodes); e) 8x8 (64 nodes).(1)

This dependency on infrastructure can limit the flexibility of deployment in certain environments. In densely populated areas or environments with high wireless interference, the proximity of nodes in a mesh grid topology may lead to increased interference levels, affecting network performance. Deploying a mesh grid network with many nodes can be costly, both in terms of equipment and installation, especially when compared to more ad-hoc or decentralized topologies [29]. Below, in Figure 2, a mesh grid network is created and then employed in the examination of routing algorithms in Section V.

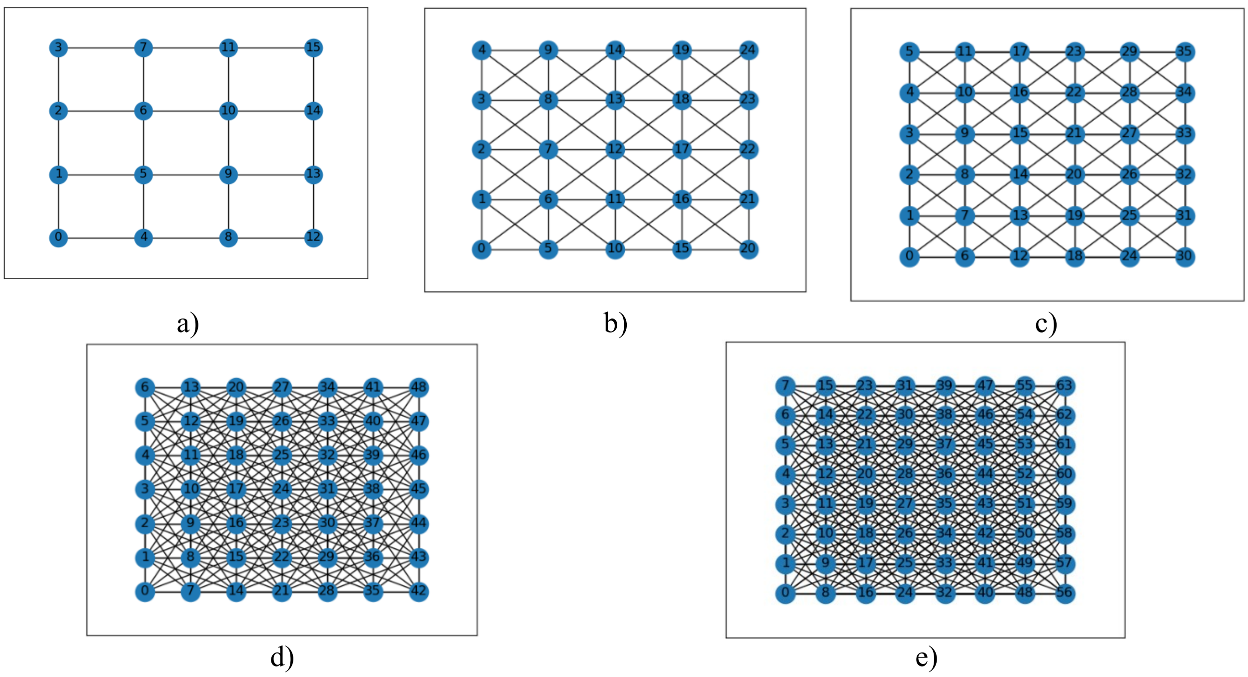

Fig.2. Mesh grid topology, where a) 4x4 (16 nodes); b) 5x5 (25 nodes); c) 6x6 (36 nodes); d) 7x7 (49 nodes); e) 8x8 (64 nodes). (2)

The "Fruchterman-Reingold" topology, named after its creators, Thomas M. J. Fruchterman and Edward M. Reingold, is a specific type of layout algorithm commonly used in graph visualization. While it is not a typical mesh network topology like random or grid, it can be applied within the context of WMN for organizing and visualizing node placements. In the Fruchterman-Reingold algorithm, nodes in a network are represented as points in a two-dimensional space, and edges between nodes are represented as lines. The algorithm simulates a physical system where nodes repel each other and edges act as springs, resulting in an equilibrium configuration where nodes are evenly spaced, and edges have minimal overlap. This topology is particularly useful for visualizing and understanding the structure of complex networks, including wireless mesh networks, as it tends to arrange nodes in a way that reveals underlying patterns and relationships. However, in practical implementations of wireless mesh networks, the Fruchterman-Reingold topology may not directly dictate the network's operational layout. Instead, it can serve as a tool for network designers and administrators to visualize and analyze network structures, aiding in optimization, troubleshooting, and planning [30]. In Figure 3 below, a topology is generated using the Fruchterman-Reingold force-directed algorithm and subsequently utilized for examining routing algorithms in Section V.

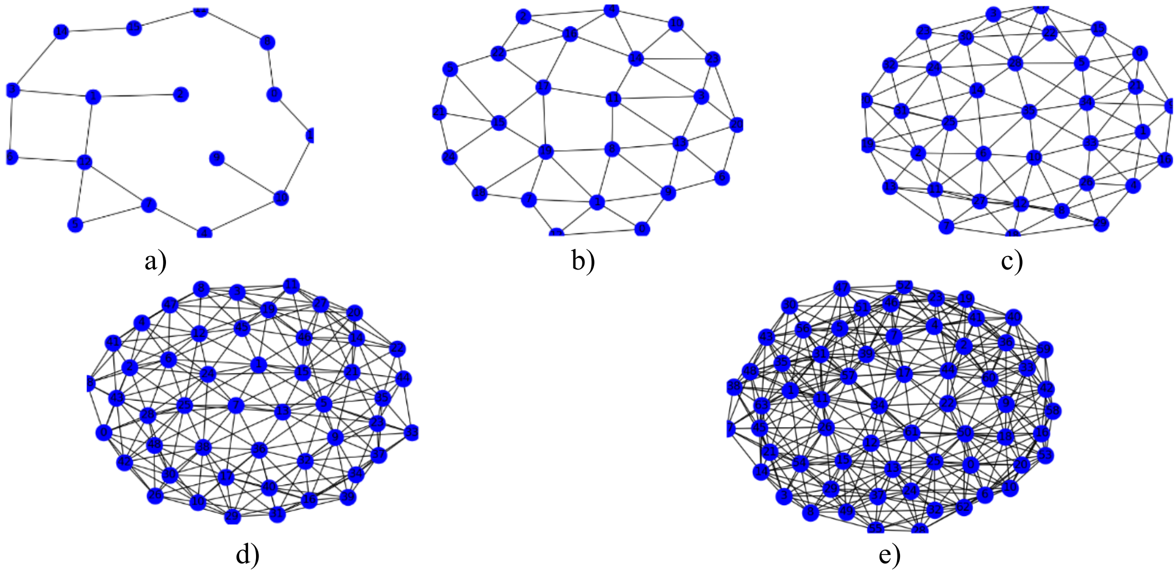

Fig.3. Fruchterman-Reingold force-directed algorithm topology, where a) 4x4 (16 nodes); b) 5x5 (25 nodes); c) 6x6 (36 nodes); d) 7x7 (49 nodes); e) 8x8 (64 nodes). (3)

In wireless mesh networks, different topologies, such as random, mesh grid, and Fruchterman-Reingold, can be utilized with various routing algorithms to optimize network performance. Each topology offers unique advantages and challenges that can be leveraged with specific algorithms to enhance data transmission, minimize latency, and improve network reliability.

5. Simulation results and discussion

In this section, we will conduct a comparative analysis of the operational effectiveness of the three routing protocols—AODV, DSDV, and OLSR—in diverse wireless mesh network topologies.

In our simulations, we employed the IEEE 802.11p standard and the Two Ray Ground Propagation Loss Model. The IEEE 802.11p is a sanctioned amendment to the IEEE 802.11 standard, designed to facilitate wireless access in vehicular environments (WAVE). The Two Ray Ground Propagation Loss Model takes into account both the direct path and a ground reflection path. The received power at a distance t is determined using equation (1).

$$P_r(d) = \frac{P_t G_t G_r h_t^2 h_r^2}{d^4 L} \tag{1}$$

where, ht and hr are the heights of the transmit and receive antennas.

Our evaluation of these 4 routing protocols mentioned above will be based on metrics such as throughput, time delay, and packet loss, providing a comprehensive assessment of their performance and suitability for WMNs. To gauge the impact of node quantity on the performance of these routing protocols, simulations were executed using NS-3.40 (ver3.14.1) on the Ubuntu 22.04 LTS platform. The simulation parameters are presented in Table 1.

Table 1. Simulation parameters

Network simulator	NS-3.40 (ver3.14.1)
Channel type	Wireless channel
Propagation model	Friis Propagation Loss Model
Network interface type	Phy/Wireless Phy
Mac type	Mac/802.11ac
Interface Queue type	Drop Tail/PriQueue
Link layer type	LL
Antenna Model	Single Antenna
Traffic type	CBR
Transport protocol	UDP
Simulation time	50 s
Packet size	1024
Simulation area	1000m*1000m
Mobility model	Constant
Adhoc protocols	OLSR version Pre-0.9.9, AODVv2, DSDV
Number of nodes in Random, MeshGrid and Fruchterman-Reingold force-directed algorithm topologies	16, 25, 36, 49, 64

A) Throughput

The results of the throughput measurement reflect the amount of data efficiently transmitted over the network over time. The throughput is determined using equation (2).

$$Throughput = (\sum successfully\ receiver\ bits\ /\ Time\ of\ simulation\ \times 1024) \qquad (2)$$

Figure 4 shows the throughput achieved by the AODV routing algorithm in various WMN topologies. The random and Reingold topology configurations demonstrate superior throughput when the optimal number of nodes is 50. These findings underscore their efficacy within the experimental context, suggesting a higher level of efficiency and reliability compared to mesh grid topology. In figure 5 OLSR routing algorithm achieves higher throughput when the optimal number of nodes is 50 in random topology compared to mesh grid and Reingold topologies, highlighting the efficacy of random topology in facilitating higher data transmission.

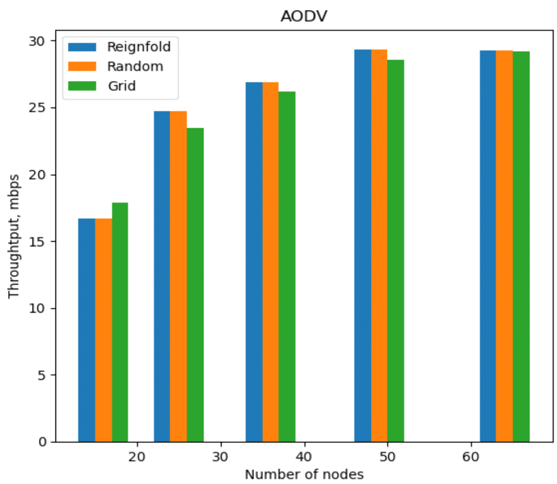

Fig.4. Throughput for AODV routing algorithm (4)

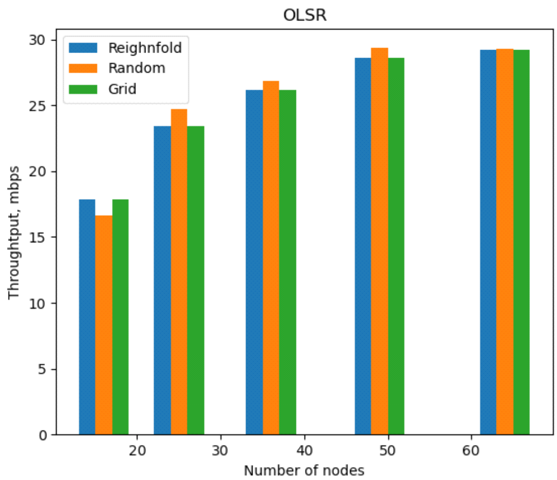

Fig.5. Throughput for OLSR routing algorithm (5)

In the following figure 6 DSDV routing algorithm exhibits superior performance in Reingold and Random topologies when the optimal number of nodes is 50 compared to mesh grid topology, indicating higher throughput speeds.

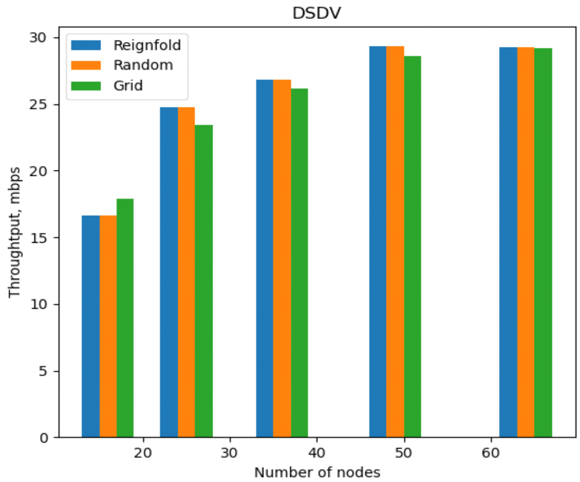

Fig.6. Throughput for DSDV routing algorithm (6)

B) Packet loss. Packet loss represents the proportion of data packets that do not reach their designated destination owing to diverse factors like network congestion or link breakdowns. The Packet loss is determined using equation (3).

$$Packet\ Lost = (\sum Packets\ send\ by\ sources\ - \sum Packets\ successfully\ received) \tag{3}$$

Figure 7 demonstrates the packet loss rates encountered with the AODV routing algorithm for each topology. It was found that packet loss reduction is observed in mesh grid topology when the number of nodes is 50 compared with two other topologies. Figure 8 illustrates the packet loss rates experienced with the OLSR routing algorithm for each topology. It was discovered that there is a decrease in packet loss in the random topology when the optimal number of nodes is 50, compared to the other two topologies.

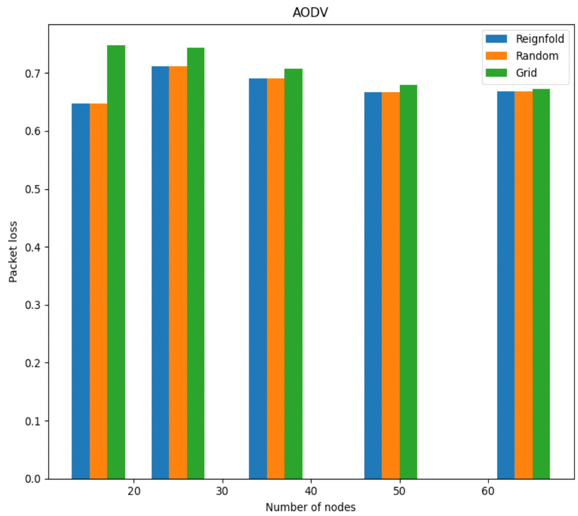

Fig.7. Packet loss for AODV routing algorithm (7)

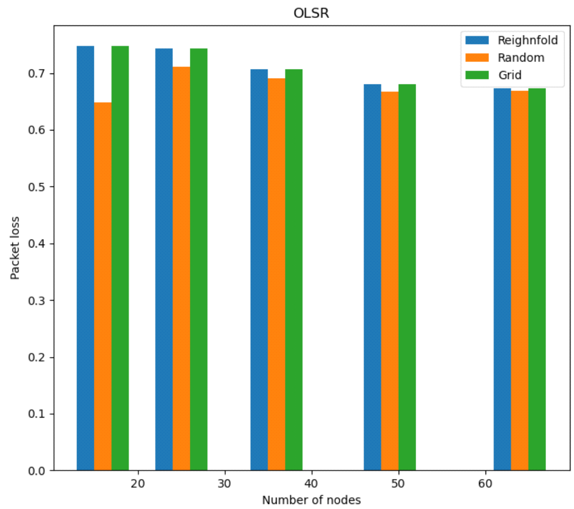

Fig.8. Packet loss for OLSR routing algorithm (8)

Figure 9 illustrates the packet loss rates observed with each topology. It was found that Reingold and random topologies for the DSDV routing algorithm consistently had the lowest packet loss rates across all tested scenarios. The optimal number of nodes at which the lowest packet loss was achieved was 50.

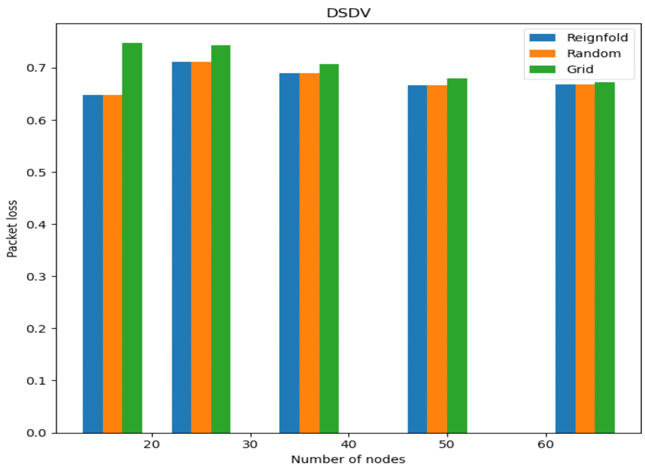

Fig.9. Packet loss for DSDV routing algorithm (9)

C) Time delay. Time delay refers to the time it takes for data packets to move from the sender to the receiver. The Time delay is determined using equation (4).

$$Time\ delay = |EndTime_i - StartTime_i| \tag{4}$$

where, $EndTime_i$ is the time that packet i was sent by the source, is received successfully by the destination and $StartTime_i$ is the time of starting to send packet i by the source. Figure 10 illustrates the time delay experienced by data packets when using the AODV routing algorithm for various topologies. When the optimal number of nodes is 60, both random and Reingold topologies exhibit the lowest time delay. Figure 11 depicts the time delay encountered by data packets when employing the OLSR routing algorithm across different topologies. In Figure 11, it is observable that with an increasing number of nodes, the time delay diminishes. When the optimal number of nodes is 60, random topologies demonstrate the lowest time delay compared to others.

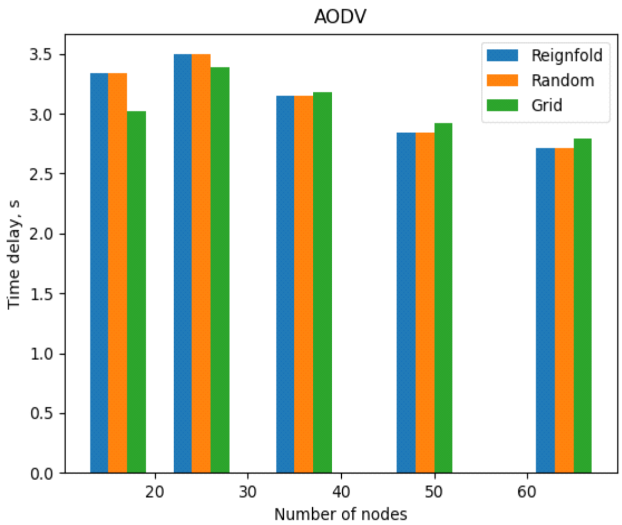

Fig.10. Time delay for AODV routing algorithm (10)

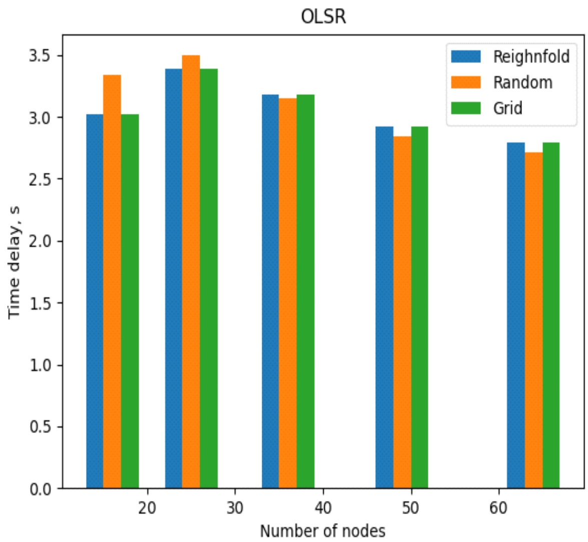

Fig.11. Time delay for OLSR routing algorithm (11)

Figure 12 illustrates the time delay experienced by data packets when utilizing the DSDV routing algorithm across various topologies. It can be observed in Figure 11 that as the number of nodes increases, the time delay decreases. At the optimal number of 60 nodes, random and Reingold topologies exhibit the lowest time delay compared to others.

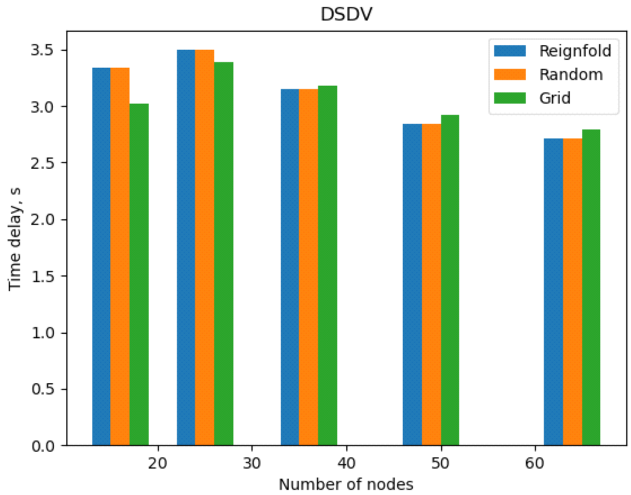

Fig.12. Time delay for DSDV routing algorithm (12)

D) Jitter. Jitter is the variation in the delay of received packets in a network. Jitter can occur due to network congestion, routing changes, or varying packet arrival times. Jitter is determined using equation (5).

$$Jitter = |(D_{i+1} - D_i) - (S_{i+1} - S_i)| \tag{5}$$

where, S_i is the time when packet i was sent from the source, and D_i is the time when it was received by the destination. Figure 13 illustrates the jitter experienced by data packets when utilizing the DSDV routing algorithm across various topologies. In the graph shown in Figure 13, it is noted that as the number of nodes in the network rises, the jitter decreases, indicating more consistent data transmission. This indicates that the mesh grid topology is more efficient when using the AODV routing algorithm compared to other topologies, especially when the optimal number of nodes is 60. Figure 14 depicts the jitter experienced by data packets when using the OLSR routing algorithm across different topologies. In Figure 14, the observed jitter values indicate the advantages of using the OLSR routing algorithm in mesh grid and Reingold topologies compared to random topology.

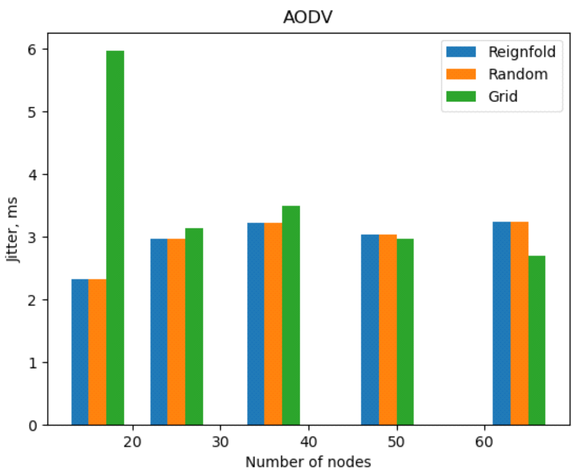

Fig.13. Jitter for AODV routing algorithm (13)

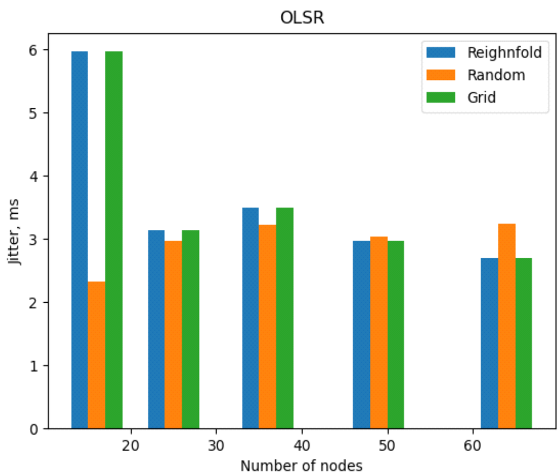

Fig.14. Jitter for OLSR routing algorithm (14)

Figure 15 illustrates the jitter encountered by data packets when employing the DSDV routing algorithm across various topologies. The graph depicted in Figure 15 suggests that for the DSDV routing algorithm, the mesh grid topology is more effective compared to the other two topologies.

.

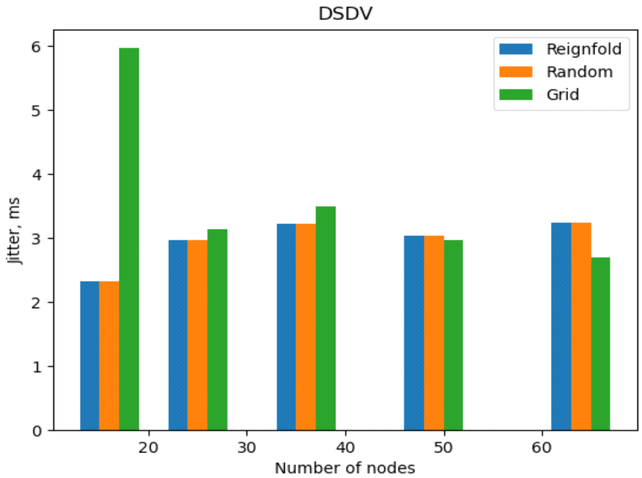

Fig.15. Jitter for DSDV routing algorithm (15)

Based on the analysis of throughput, jitter, time delay, and packet loss across various topologies, the following conclusions can be drawn about the suitability of different routing algorithms. For the AODV routing algorithm, the mesh grid topology appears to be the most suitable, as it offers reduced packet loss and stable data transmission, especially with around 60 nodes. For the OLSR routing algorithm, the random topology performs better in terms of throughput and time delay with around 50 to 60 nodes. For the DSDV routing algorithm, both random and Reingold topologies show promising results across various metrics, particularly with around 50 to 60 nodes.

6. Conclusion

In summary, this study aimed to assess the efficacy of AODV, DSDV, and OLSR routing algorithms across diverse Wireless Mesh Network (WMN) topologies using simulations in the NS-3 environment. Through extensive analysis, valuable insights into the performance of these protocols in different scenarios were gained. Initially, it was noted that the mesh grid topology proves optimal for the AODV routing algorithm, especially with approximately 60 nodes, offering minimized packet loss and stable data transmission, thus ensuring reliable network communication. Additionally, the OLSR routing algorithm exhibited superior performance in random topologies, particularly with around 50 to 60 nodes, demonstrating higher throughput and reduced time delay compared to other configurations. This underscores the effectiveness of random topologies in facilitating efficient data transmission. Lastly, for the DSDV routing algorithm, both random and Reingold topologies showed promising outcomes across various metrics, particularly with approximately 50 to 60 nodes, featuring lower packet loss rates and efficient data transmission, thus making them viable choices for deploying DSDV routing in WMNs.

The study provides valuable insights into the suitability of routing algorithms across different WMN topologies, offering guidance for network designers and administrators in optimizing network performance and reliability. Further research in this area can lead to advancements in routing protocols and network design, ultimately enhancing the functionality and efficiency of Wireless Mesh Networks in diverse applications and environments.

Conflict of interest statement

We want to make it clear that we have absolutely no conflicts of interest that could sway the findings or conclusions presented here. Financially, personally, or in terms of authorship, there's nothing that could interfere with the integrity of our work. It's important to us that our research is seen as unbiased and credible.

CRediT author statement

Turlykozhayeva D.A.: Conceptualization, Supervision, Akhtanov S.N.: Data Curation, Writing - Original Draft, Baigaliyeva A.N.: Writing - Review & Editing, Temesheva S.A.: Writing - Review & Editing, Zaidyn M.: Data Curation, Writing - Original Draft, Ussipov N.M.: Data Curation, Writing - Original Draft. The final manuscript was read and approved by all authors.

Acknowledgments

We would like to express deepest appreciation to the Research Institute of Experimental and Theoretical Physics at al-Farabi Kazakh National University for their invaluable support in providing computing resources of the Department of Physics and Technology for this study.

Funding

The research received funding from the Ministry of Science and Higher Education of the Republic of Kazakhstan, under grant number AP19674715.

References

1 Parvin J. R. (2019) An overview of wireless mesh networks. *Wireless mesh networks- security, architectures and protocols*. DOI:10.5772/intechopen.83414.

2 Taleb S.M., Meraihi Y., Gabis A.B., Mirjalili S., Ramdane-Cherif A. (2022) Nodes placement in wireless mesh networks using optimization approaches: a survey. *Neural Computing and Applications*. 34(7), 5283-5319. DOI:10.1007/s00521-022-06941-y.

3 Bhushan S., Singh A.K., Vij S. (2019) Comparative study and analysis of wireless mesh networks on AODV and DSR. *In 2019 4th International conference on internet of things: smart innovation and usages* (IoT-SIU), 1-6. DOI:10.1109/IoT-SIU.2019.8777466.

4 Kaur J., Singh H. (2023). Several Routing Protocols, Features and Limitations for Wireless Mesh Network (WMN): A Review. In ICDSMLA 2021: *Proceedings of the 3rd International Conference on Data Science, Machine Learning and Applications*, 187-200. DOI:10.1007/978-981-19-5936-3_18.

5 Khairi T.W., Al-Zubidi A.F., Ahmed E.Q. (2021) Modified Multipath Routing Protocol Applied On Ns3 Dcell Network Simulation System. *International Journal of Interactive Mobile Technologies*, 15(10). DOI:10.3991/ijim.v15i10.22703.

6 Taterh S., Meena Y., Paliwal G. (2020) Performance analysis of ad hoc on-demand distance vector routing protocol for mobile ad hoc networks. *Computational Network Application Tools for Performance Management*, 235-245. DOI:10.1007/978-981-32-9585-8_20.

7 Abbas T., Qamar F., Hindia M.N., Hassan R., Ahmed I., Aslam M.I. (2020) Performance analysis of ad hoc on-demand distance vector routing protocol for MANET. *Proceeding of the 2020 IEEE student conference on research and development (SCOReD)*. 194-199. DOI:10.3390/engproc2023032005.

8 Nurlan Z., Zhukabayeva T., Othman M., Adamova, A., Zhakiyev N. (2021) Wireless sensor network as a mesh: Vision and challenges. *IEEE Access*. 10, 46-67. DOI:10.1109/ACCESS.2021.3137341.

9 Chai Y., Zeng X.J. (2020) Delay-and interference-aware routing for wireless mesh network. *IEEE Systems Journal*. 14(3), 4119-4130. DOI: 10.1109/JSYST.2020.2966795.

10 Khudayer B.H., Alzabin L.R., Anbar M., Tawafak R.M., Wan T.C., AlSideiri A., Al-Amiedy T.A. (2023) A Comparative Performance Evaluation of Routing Protocols for Mobile Ad-hoc Networks. *International Journal of Advanced Computer Science and Applications.* 14(4). DOI: 10.14569/IJACSA.2023.0140449.

11 Singh M., Singh M. (2019) Routing protocol for WMNs. *Node-to-Node Approaching in Wireless Mesh Connectivity.* 15-20. DOI: 10.1007/978-981-13-0674-7.

12 Rozy N.F., Ramadhiansya R., Sunarya P.A., Rahardja U. (2019) Performance Comparison Routing Protocol AODV, DSDV, and AOMDV with Video Streaming in Manet. *Proceeding of the 7th international conference on cyber and IT service management (CITSM)*. 1-6. DOI:10.1109/CITSM47753.2019.8965386.

13 Shrivastava P.K., Vishwamitra L.K. (2021) Comparative analysis of proactive and reactive routing protocols in VANET environment. *Measurement: Sensors*. 16, 100051. DOI: 10.1016/j.measen.2021.100051.

14 AL-Hasani B., Waheed B. (2022) Comparative study and performance investigation of MANET routing protocols. *International Journal of Nonlinear Analysis and Applications*. 13(2), 1953-1964.

15 Gupta N., Vaisla K.S., Jain A., Kumar A., Kumar R. (2022) Performance Analysis of AODV Routing for Wireless Sensor Network in FPGA Hardware. *Computer Systems Science & Engineering*, 40(3). DOI:10.32604/csse.2022.019911.

16 Kurniawan A., Kristalina P., Hadi M.Z.S. (2020) Performance analysis of routing protocols AODV, OLSR and DSDV on MANET using NS3. *Proceeding of the international electronics symposium (IES2020).* 199-206. DOI: 10.1109/IES50839.2020.9231690.

17 Arega K.L., Raga G., Bareto R. (2020) Survey on performance analysis of AODV, DSR and DSDV in MANET *Computer Engineering and Intelligent Systems*. 23-32. DOI: 10.7176/CEIS/11-3-03.

18 Rajeswari A.R. (2020). A mobile ad hoc network routin protocols: A comparative study. *Recent trends in communication networks.* 6(1), 1-24. DOI: 10.5772/intechopen.92550.

.

19 Singh R., Singh N., Dinker A.G. (2021) Performance analysis of TCP variants using AODV and DSDV routing protocols in MANETs. Recent advances in computer science and communications. *Formerly: Recent Patents on Computer Science*. 14(2), 448-455. DOI: 10.2174/2666255813666190911114130.

20 Singh R., Singh N. (2020) Performance assessment of DSDV and AODV routing protocols in mobile adhoc networks with focus on node density and routing overhead. *Proceeding of the International Conference on Emerging Smart Computing and Informatics (ESCI).* 298-303. DOI: 10.1109/ESCI48226.2020.9167627.

21 Afzal K., Tariq R., Aadil F., Iqbal Z., Ali N., Sajid M. (2021) An optimized and efficient routing protocol application for IoV. *Mathematical Problems in Engineering*. 2021, 1-32. DOI:10.1155/2021/9977252.

22 Arega, K.L., Raga G., Bareto R. (2020) Survey on performance analysis of AODV, DSR and DSDV in MANET. *Computer Engineering and Intelligent Systems,* 11(3), 23-32. DOI: 10.7176/CEIS/11-3-03.

23 Wheeb A.H., Al-Jamali N.A.S. (2022) Performance analysis of OLSR protocol in mobile ad hoc networks. *iJIM*. 16(01), 107. DOI: https://doi.org/10.3991/ijim.v16i01.26663.

24 Hussain T., Ali I., Arif M., Baseer S., Pervez F., Rehman Z.U. (2020) An investigation of the performance optimized link state routing protocol on the basis of mobility models. *Journal of mechanics of continua and mathematical sciences.* 15(9), 306-327. DOI: 10.26782/jmcms.2020.09.00025.

25 Shaban A.M., Kurnaz S., Shantaf A.M. (2020). Evaluation DSDV, AODV and OLSR routing protocols in real live by using SUMO with NS3 simulation in VANET. *Proceeding of the International Congress on Human-Computer Interaction, Optimization and Robotic Applications (HORA).* 1-5. DOI: 10.30534/ijatcse/2021/591032021.

26 Akhtanov S., Turlykozhayeva D., Ussipov N., Ibraimov M., Zhanabaev Z. (2022) Centre including eccentricity algorithm for complex networks. *Electronics Letters.* 58(7), 283-285. DOI: 10.1049/ell2.12424.

27 Turlykozhayeva D., Akhtanov S., Ussipov N., Akhmetali A., Bolysbay A., Shabdan Y. (2023). Routing Algorithm for Software Defined Network Based on Boxcovering Algorithm. *Proceeding of the 10th International Conference on Wireless Networks and Mobile Communications (WINCOM*). 1-5. DOI: 10.1109/WINCOM59760.2023.10322960.

28 Turlykozhayeva D., Ussipov N., Baigaliyeva A., Temesheva S., Bolysbay A., Abrakhmatova G., Akhtanov S. (2024). Routing metric and protocol for wireless mesh network based on information entropy theory. *Eurasian phys. tech. j., 20.* 4(46), 90–98. DOI: 10.31489/2023No4/90-98.

29 Zhanabaev Z., Akhtanov S., Turlykozhayeva D., Ussipov N., Ibraimov M. (2022) Cluster pourer based on eccentricity. *Eurasian phys. tech. j.* 19, 3(41), 84–90. DOI: 10.31489/2022No3/84-90.

30 Mathieu Jacomy (2015) Fruchterman Reingold. Retrieved from Online website: https://github.com/gephi/gephi/wiki/Fruchterman-Reingold

---

AUTHORS' INFORMATION

Turlykozhayeva, Dana Abdikumarovna - PhD student, Researcher, Lecturer, Department of Physics and Technology, al-Farabi Kazakh National University, Kazakhstan; ORCID iD: 0000-0002-7326-9196; turlykozhayeva.dana@kaznu.kz

Akhtanov, Sayat Nusipbekovich - PhD, Researcher, Senior Lecturer, Department of Physics and Technology, al-Farabi Kazakh National University, Kazakhstan; ORCID iD: 0000-0002-9705-8000; ahtanov.saiyat1@kaznu.kz

Baigaliyeva, Aiym Nurlanovna - Master student, Department of Physics and Technology, al-Farabi Kazakh National University, Kazakhstan; aiymbglva@mail.ru

Temesheva, Symbat Aidynkyzy - Master of technical sciences, Department of Physics and Technology, al-Farabi Kazakh National University, Kazakhstan; ORCID iD 0009-0000-2795-9586; symbat.temesheva@gmail.com

Zhexebay, Dauren - PhD, Researcher, Senior Lecturer, Department of Physics and Technology, al-Farabi Kazakh National University, Kazakhstan; ORCID iD: 0009-0006-8505-7277; Dauren.Zheksebay@kaznu.edu.kz

Zaidyn, Marat - Bachelor student, Department of Physics and Technology, al-Farabi Kazakh National University, Kazakhstan; ORCID iD 0009-0006-8505-7277; maratzafden@gmail.com

Ussipov, Nurzhan Musayipuli - PhD student, Researcher, Lecturer, Department of Physics and Technology, al-Farabi Kazakh National University, Kazakhstan; ORCID iD: 0000-0002-2512-3280; ussipov.nurzhan@kaznu.kz

Skabylov, Alisher A. - PhD, Researcher, Senior Lecturer, Department of Physics and Technology, al-Farabi Kazakh National University, Kazakhstan; ORCID iD: 0000-0002-5196-8252; Alisher.Skabylov@kaznu.edu.kz