A SYSTEMATIC REVIEW OF AD-HOC ON-DEMAND DISTANCE VECTOR ROUTING PROTOCOL FOR PERFORMANCE IMPROVEMENT IN MOBILE AD-HOC NETWORKS

Patrick M. Njoroge, John G. Ndia and Peter M. Mwangi

Murang'a University of Technology/School of Computing and Information Technology, Murang'a, Kenya

ABSTRACT

Routing protocols are fundamental in establishing linkages and communication amongst nodes in Mobile Ad-hoc Networks (MANET). Since Ad-hoc On-demand Distance Vector (AODV) protocol shuns loops and minimizes route broadcasts its predominantly utilized in MANET. This systematic review sought to uncover approaches employed in extending AODV for performance improvement in MANET, their limitations, and AODV characteristics that are extendable. Barbara Kitchenham's original guidelines (2007) guided the research, while studies were retrieved from IEEE, Science Direct, Wiley, Semantic Scholar, ACM Digital Library, EBSCOhost, and Google Scholar databases. The common approaches employed are consideration of parameters to improve quality of service, artificial intelligence and machine learning, and use of the signal strength. The limitations of the approaches can be optimized for improved performance in terms of reduced control traffic and packet loss, efficient bandwidth and memory utilization, reduced processing costs, and energy consumption. The AODV characteristics commonly extended are route discovery, selection, and maintenance. Future work could investigate clustering and zoning, and caching mechanisms approaches to enrich the reliability, performance, and efficiency of AODV protocol.

KEYWORDS

AODV, AODV modification, AODV extension, Performance improvement, Performance enhancement, AODV Characteristic, Approach, and MANET.

1. INTRODUCTION

The Mobile Ad-hoc Network (MANET), are networks that self-configures, lacks centralized control, self-organizes, and possesses a very dynamic topology [1] [2] [3] [4] [5]. Because of these unique characteristics, MANET has found application in search and rescue operations, law enforcement, disaster management, healthcare, military battlefield communications, smart homes, robotics, agriculture, smart cities, virtual navigation, and mobile conferencing [6] [7] [8] [9]. However, MANETs face several challenges which include routing overheads, dynamic topology due to node mobility, link breakages, security threats, nodes' limited battery power, packet loss, limited bandwidth, scalability problems, transmission range constraints, and memory constraints [2] [10] [11] [12]. Therefore, the routing protocols in MANET which play a critical role in establishing the basic linkages and communication amongst the mobile nodes [11], are broadly classified as reactive, proactive, and hybrid protocols [13] [14]. Evidence in literature depicts that reactive protocols as compared to either proactive or hybrid protocols are highly scalable, have less routing overheads, have lower memory and bandwidth requirements; and that

they discover routes on demand [9] [14] [15] [16]. This makes reactive protocols the most predominantly utilized protocols in MANET, and in particular Ad-hoc On-demand Distance Vector (AODV) protocol [13] [17] [18].

The Ad-hoc On-demand Distance Vector(AODV) routing protocol initiates routing path discovery whenever a node in the network has data to send to any destination [9] [19]. The protocol performs routing operation fundamentally in two steps namely the route discovery process and route maintenance process [20]. A source node with packets to forward, commences a route discovery by sending route request (RREQ) messages to all its neighbor nodes [4]. The RREQ is then forwarded further among the neighboring nodes, in search of the path to the destination [9]. The intermediary nodes, on receiving a packet first update their routing information before forwarding the packet. The receiving node also checks to confirm whether the route request message had been processed previously, and if so it is discarded [16]. When the target node receives the RREQ, it sends back a unicast route reply (RREP) message to the source node or originator of the route request.

The protocol does not pre-build a route but discovers the route through the hop-by-hop routing, and it uses sequence numbers to determine the newest routes and avoid routing loops [9], and the newest route entries replace older ones in the routing table. When an intermediate node experiences a broken link with its next hop neighbor, in an active route, it initiates the route maintenance process by broadcasting a route error (RERR) message, and the route entry for that destination is marked as invalid. When the originator node receives the route error message, the transmission of data via the affected route is halted, and the route discovery process is reinitiated with a different sequence number [9] [20]. Through the use of periodic hello messages, nodes can detect the link status of their neighbors [16]. Whenever a node does not broadcast the hello message, the neighbors take it that the node is unreachable or down [21] [22].

The rest of the paper is organized as follows: Section two presents a discussion on the related works, section three discusses the research method, section four focusses on the study discussion, and section five focusses on the study conclusion and future work.

2. RELATED WORKS

There exist some reviews in the literature on AODV extensions or modifications for performance improvement in MANET. Srivastava and Srivastava [23] reviewed algorithms that employ mesh structure to provide for the discovery of multiple alternate routing paths. The discovery of multiple routing paths can assist in the reduction of routing overheads and route discovery latency. The study presents a description of five (5) AODV-based backup routing algorithms and their comparison based on mesh structure and multipath parameters. The main scope of the journal article is restricted to the review of AODV-based backup schemes. The paper's main flaw is that it lacks a research methodology, and thus can be subject to author bias.

Alameri et al., [24] conducted a systematic review of modifications to the AODV routing discovery process based on Preferred Reporting Items for Systematic Reviews and MetaAnalyses (PRISMA). The paper examined some existing modifications to the AODV route discovery process, highlighting their mode of operation and impact on network performance. However, it's notable that the review addresses modifications to the AODV route discovery process, while ignoring strategies for performance improvement which could emanate from modifications of other key characteristics of AODV such as route selection, route maintenance, routing metric, and time to live among others.

The authors [18], performed a review of recent advances in AODV protocol path optimization algorithms for MANET. The paper reviewed five (5) recent AODV extension algorithms dealing with path optimization for MANET and exposed their weaknesses and their network performance. The algorithms were compared with each other against performance metrics namely routing overhead, throughput, packet delivery ratio, and end-to-end delay. Further, the study's scope is restricted to the review of path optimization algorithms. The paper's main flaw is that it lacks a methodology, and is thus subject to authors' bias.

3. RESEARCH METHOD

The study sought to perform a systematic literature review to expose the approaches employed in extending AODV, their limitations, and the AODV characteristics that are extended for performance improvement in MANET. The research was based on Barbara Kitchenham's original guidelines (2007), since it allows for a comprehensive, unbiased, and repeatable review process. The study is categorized as a secondary study since it aims to review primary studies on approaches employed in extending AODV for performance improvement in MANET. Therefore, the focus is on uncovering the approaches in literature employed in extending or modifying AODV protocol to optimize performance in MANET, understanding their limitations and pinpointing AODV characteristics extended in the approaches. This will expose practical and relevant technological approaches and best practices in AODV protocol aimed at performance improvement. The process involved planning, conducting, and reporting the review.

3.1. Planning for the Review

The researcher established the research aim, the research questions, the search strategy, and the inclusion and exclusion criteria in this phase. Further the online databases to utilize were selected.

3.1.1. Aim of the Systematic Review

The systematic review sought to expose the approaches employed in extending AODV, their limitations, and the AODV characteristics that are extended for performance improvement in MANET.

3.1.2. Research Questions

The following research questions were crafted to aid in achievement of the research objective.

a. What approaches are employed in extending AODV for performance improvement in MANET?
b. What are the limitations of the approaches employed in extending AODV for performance improvement in MANET?
c. What characteristics of the AODV routing protocol are extended for performance improvement in MANET?

3.1.3. Search Strategy

A search strategy was developed using the keywords and Boolean operators as indicated below, to aid in the retrieval of the relevant papers from the digital databases. The use of the multiple keywords ensured that no relevant studies were missed out.

(AODV OR AODV Enhancement OR AODV Optimization OR AODV Modifications OR AODV Extension) AND (Performance OR Performance Improvement OR Performance Enhancement OR Performance Optimization) AND (In MANET)

3.1.4. Inclusion and Exclusion Criteria

The criteria for including or excluding studies was established as follows:

Inclusion Criteria

- Peer-reviewed journal publications or published conference proceedings.
- Studies published between the years 2014 and 2024
- Studies about AODV, AODV Extension or AODV Modifications or AODV Enhancement and Performance in MANET
- Comparative studies about extended, enhanced, optimized, or modified AODV and other routing protocols in MANET
- Studies addressing at least two of the performance metrics under consideration namely throughput, packet delivery ratio, packet loss, routing overhead, and end-to-end delay

Exclusion Criteria

- Journal publications not peer-reviewed and unpublished conference proceedings
- Non-English publications
- Duplicate Studies
- Journal publications or conference proceedings not reviewing AODV and Performance in MANET.
- Journal publications or conference proceedings not about MANET
- Studies older than ten years
- Studies addressing one or none of the performance metrics under consideration

3.2. Conducting the Review

This involves carrying out the search process, selection of relevant studies, study quality assessment, data extraction, and data synthesis.

3.2.1. Search Process

The study considered the following digital libraries namely IEEE Xplore, EBSCOhost, Wiley, Science Direct, Semantic Scholar, ACM Digital Library, and Google Scholar. These databases were selected because they possessed extensive literature of the knowledge domain under study. A search was done on each of the digital libraries at a time. The crafted search strategy was employed in the search process to assist in retrieving journal articles and conference proceedings of interest, coupled with the year of publication between 2014 and 2024. The studies retrieved were written in the English language. The retrieved journal articles and conference proceedings were subjected to subsequent analysis and reporting.

3.2.2. Selection of Relevant Studies

The retrieved journal articles and conference proceedings were further subjected to relevant inclusion and exclusion criteria. Firstly, the titles and abstract were examined, and subject to the following criteria;

- Journal publications or conference proceedings not reviewing AODV and Performance in MANET were excluded
- Journal publications or conference proceedings not about MANET were excluded
- Studies addressing one or none of the performance metrics under consideration were excluded
- Duplicate Studies were dropped
- Studies not about AODV, AODV Extension or AODV Modifications or AODV Enhancement and Performance in MANET were excluded

3.2.3. Study Quality Assessment

The selected studies that is, relevant journal articles and conference proceedings were further subjected to the research quality assessment. The quality threshold for the study was set as the ability of the selected journal article or conference proceeding to answer all the study questions. Any study which did not meet the quality threshold criteria was excluded. To determine how well each study satisfied the quality criteria, the researcher used the following approach;

- To satisfy research question 1(RQ1), the researcher read the abstract, methodology, results, and discussion sections documenting the approaches used in extending AODV for performance improvement in MANET
- To satisfy research question 2(RQ2), the researcher read the results, discussion, conclusion, and future works sections documenting the limitations of the approaches.
- To satisfy research question 3(RQ3), the researcher read the methodology, results, and discussion sections documenting the characteristics of AODV that are extended for performance improvement in MANET

3.2.4. Data Extraction and Synthesis

After the study quality assessment, data was extracted from the chosen studies using spreadsheets. These fields were extracted namely the database, title, authors, publication year, research methods, results, conclusion and future works. A thematic analysis approach was employed to identify patterns and themes within the data. This process involved classifying data based on approaches employed in extending AODV for performance improvement in MANET, limitations of the approaches, performance impact, and characteristics of the AODV protocol extended. The extracted data finally was synthesized to answer the research questions and achieve the objectives of the research. Table 1, depicts the final list of studies for review after the quality assessment.

Table 1. List of Included Studies after Quality Assessment

Digital Library /Database	**No. of Studies Retrieved (after Search Process)**	**No. of Relevant Studies Selected**	**No. of Studies Included after Quality Assessment**
IEEE Xplore	646	70	49
EBSCOhost	197	29	11
Semantic Scholar	173	9	4
Wiley	180	9	3
Science Direct	661	6	6
ACM Digital Library	219	4	2
Google Scholar	799	18	8
Total	**2875**	**145**	**83**

Fig. 1, portrays the flowchart for the selection and evaluation process of the relevant studies.

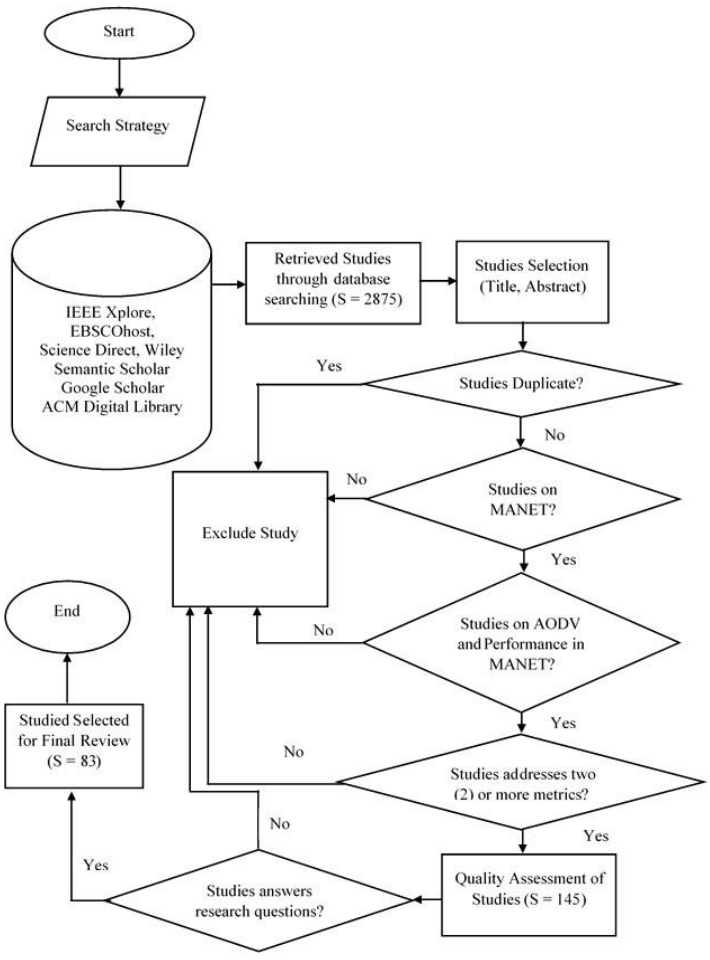

Fig. 1. Flowchart for Selection and Evaluation of Studies

3.3. Reporting and Review

This section presents the findings from the studies considered in the research in line with the research questions.

3.3.1. RQ1: What approaches are employed in extending AODV for performance improvement in MANET?

The first approach was consideration of parameters to improve the quality of service in MANET. Twenty (20) out of eighty-three (83) studies reviewed employed the approach. To improve on quality of service and thus guarantee efficiency in data transmission and utilization of network resources, evidence from the studies reviewed shows that AODV route discovery, route maintenance and route selection processes were extended or modified to consider additional parameters such as route stability, bandwidth, mobility, signal strength, link quality, link data rate, load, direction, buffer information, total remaining energy, thermal noise, cochannel interference, delay, link throughput, battery power, link loss rate, travel time and nodes [7] [25] [26] [27] [28] [29] [30] [31] [32] [33] [34] [35] [36] [37] [38] [39] [40] [41] [42] [43].

The second approach was artificial intelligence and machine learning with twenty (20) out of eighty-three (83) studies reviewed addressing the approach. Ant Colony Optimization (ACO) Algorithm was addressed by [44] [45] [46] [47] [48] [49] [50] [51], followed by the Cuckoo Search Algorithm [52] [53] [54], Use of Genetic Algorithm [55] [56] [57], Use of Fuzzy Logic and Adaptive Neural Fuzzy Inference [58] [59] [60], Reinforcement Learning [61], African Buffalo Optimization [62] and Fruit Fly Optimized Algorithm [63].

The third approach was the consideration of signal strength with nine (9) out of eighty-three (83) studies reviewed addressing the approach [64] [65] [66] [67] [68] [69] [70] [71] [72]. The fourth approach employed was multiple paths discovery with six (6) out of eighty-three (83) studies reviewed addressing the approach [73] [74] [75] [76] [77] [78]. This tied with the fifth approach which was congestion control mechanisms which had six (6) out of eighty-three (83) studies reviewed addressing the approach as well [79] [80] [81] [82] [83] [84].

The sixth approach was the consideration of energy levels of nodes (remaining energy) with five (5) out of eighty-three (83) studies reviewed addressing the approach [85] [86] [87] [88] [89]. The seventh approach the use of Global Positioning Systems (GPS) had four (4) out of eighty-three (83) studies reviewed addressing the approach [90] [91] [92] [93], while approach number eight the use of mobile agents had three (3) out of eighty-three (83) studies reviewing it [94] [95] [96] as well as approach number nine use of forwarding probabilistic schemes which had three (3) studies reviewing it [97] [98] [99].

The tenth approach clustering and zoning as well as the eleventh approach node to node distance calculations each had two (2) studies reviewing them [100] [101] and [102] [103] respectively. The node-to-node distance calculation was done using Euclidean and Manhattan distances. The twelfth approach was the use of the time to live factor, the thirteenth approach was the selection of a backup node, and the fourteenth approach was the use of a caching mechanism each had one (1) study reviewing them [104], and [105] and [106] respectively.

Table 2. AODV Performance Improvement Approaches

Approach	**No. of Studies**	**Percent (%)**
Consideration of parameters to improve Quality of Service(QoS)	20	24
Artificial Intelligence and Machine Learning	20	24
Consideration of signal strength	9	12
Multiple paths discovery	6	7
Congestion control mechanisms	6	7
Consideration of energy levels of nodes (remaining energy)	5	6
Use of Global Positioning Systems (GPS)	4	5
Use of mobile agents	3	4
Use of forwarding probabilistic schemes	3	4
Clustering and zoning	2	2
Node-to-node distance calculations	2	2
Use of time to live factor	1	1
Selection of a backup node	1	1
Use of the caching mechanism	1	1
Total	**83**	**100**

3.3.2. RQ2: What are the limitations of approaches employed in extending AODV for performance improvement in MANET?

The limitations of approaches employed in extending AODV protocol are as shown in Table 3.

Table 3. Limitations of Techniques employed for extending AODV

Approach	**Limitation(s)**	**References**
Consideration of parameters to improve Quality of Service(QoS)	The approach should incorporate extra parameters for the optimization of route discovery, maintenance, and selection processes.	[7] [25] [26] [27] [28] [29] [30] [31] [32] [33] [34] [35] [36] [37] [38] [39] [40] [41] [42] [43]
Artificial Intelligence and Machine Learning	The approach should be refined to reduce routing overheads and optimize data processing and energy consumption since MANETs are constrained in terms of bandwidth and battery power. The approach should incorporate additional parameters to enhance route selection decision-making. Security be enhanced during communication.	[44] [45] [46] [47] [48] [49] [50] [51] [52] [53] [54] [55] [56] [57] [58] [59] [60] [61] [62] [63]
Consideration of signal strength	The approach should be enhanced to consider additional parameters thus optimize routing overheads and conserve node energy and efficiently handle mobility issues	[64] [65] [66] [67] [68] [69] [70] [71] [72]

Approach	Limitation(s)	References
Multiple paths discovery	The approach should be optimized to allow for efficient use of limited memory and bandwidth resources in MANETs.	[73] [74] [75] [76] [77] [78]
Congestion control mechanisms	The approach should incorporate extra parameters for the optimization of route discovery, maintenance, and selection processes . The approach be optimized to efficiently monitor traffic loads and active paths.	[79] [80] [81] [82] [83] [84]
Consideration of energy levels of nodes (remaining energy)	The approach should consider additional parameters to optimize routing overhead issues, congestion control, and packet loss	[85] [86] [87] [88] [89]
Use of Global Positioning Systems (GPS)	The approach should be refined to optimize data processing, memory utilization, and energy consumption since MANETs are constrained in terms of processing power, memory, and battery power. Security be enhanced during communication.	[90] [91] [92] [93]
Use of mobile agents	The approach should be refined to optimize data processing and energy consumption since MANETs are constrained in terms of processing power and battery power. Security be enhanced in the technique.	[94] [95] [96]
Use of forwarding probabilistic schemes	The approach should incorporate extra parameters to reduce routing overheads and optimize the route discovery process in MANET .	[97] [98] [99]
Clustering and zoning	The approach should be refined to optimize cluster/zone sizes. If the size is too small performance may be affected due to large routing overheads while if too large reliability of the network is compromised. The approach needs energy optimization for a prolonged network lifetime	[100] [101]
Node-to-node distance calculations	The approach is inadequate for sparse networks. Further with the growth in the number of dimensions in your vector, the calculation of distance between vectors does not make sense anymore. The approach should consider additional parameters to optimize routing decisions.	[102] [103]
Use of time to live factor	The approach should be optimized to determine appropriate TTL values. Misconfigured TTL values can cause excess traffic, delays, or packet loss in the MANETs. Low TTL value can cause packet loss while high TTL can cause excess traffic in the network	[104]
Selection of a backup node	The approach should be optimized to avoid high overheads due to maintenance and update of routing information. High overheads can consume the limited bandwidth available in MANET	[105]
Use of the Caching mechanism	The approach is prone to high overheads due to frequent topological changes in MANET. A change in topology could trigger extra overheads for updating and maintaining the doublelinked list. This can lead to high processing and memory costs. Further routes in the cache could be stale, causing inefficiencies in the network	[106]

3.3.3 RQ3: What characteristics of the AODV routing protocol are extended for performance improvement in MANET?

The study findings of the AODV characteristics that were extended or modified for performance improvement in MANET is presented below.

a. The Route Discovery: Routes discovered through broadcasting of route request messages [29] [32] [37] [52] [61] [85] [90] [94] [95] [97] [101].
b. The Route Maintenance: This involves strategies to repair a broken link, as well as circulation of network topological information through sharing of hello messages [60] [64] [67] [82].
c. Time to live: Discovery of routing path done through consideration of time to live factor [104]
d. The Route Selection: AODV by default uses the minimum hop count as the metric for route selection coupled with the highest sequence number which indicates the freshest route. The route selection criteria were modified to incorporate other parameters in the route selection logic such as residual energy of nodes, buffer information, traffic load, node mobility, signal noise ratio, delay, bandwidth, link quality, battery power, queue length, and signal strength among others [31] [35] [38] [40] [41] [43] [83] [88].

Table 4. AODV Characteristics

AODV Characteristic	No. of Studies	Percent (%)
Route Discovery	47	57
Route Selection	17	20
Route Discovery and Route Selection	13	16
Route Maintenance	4	5
Time to live	1	1
Route Discovery and Route Maintenance	1	1
Total	**83**	**100**

4. DISCUSSION

The study aimed to review the available scholarly work on approaches employed in extending AODV for performance improvement in MANET and their limitations. Further, the study sought to reveal the AODV protocol characteristics commonly extended for performance improvement in MANET. Data was gathered from published studies, between the years 2014 and 2024, and Barbara Kitchenham's original guidelines (2007), were adopted to guide the research. After consideration of the inclusion and exclusion criteria and study quality assessment, eighty-three (83) papers were chosen for final review. The study discussions are summarized as follows:

RQ1. The first research question was reviewing approaches employed in extending AODV for performance improvement in MANET. The study results revealed that there are several approaches in literature employed in extending AODV for performance improvement in MANET. The approaches are depicted in Table 2. Consideration of parameters to improve QoS was addressed by 24% of studies reviewed. To improve on quality of service and thus guarantee efficiency in data transmission and utilization of network resources, AODV route discovery, maintenance, and selection processes were extended or modified to consider additional parameters. The second approach artificial intelligence and machine learning was also addressed by 24% of the studies while the third approach consideration of signal strength was addressed by

12% of the studies. The fourth and the fifth approaches namely multiple paths discovery and congestion control mechanisms each was reviewed by 7% of the studies. The study provides insights into approaches employed in extending AODV for performance improvement in MANET, which could be helpful for researchers who intend to undertake studies in AODV performance and utilization. The study further provides more approaches than available in the reviewed literature. Further, with a significant number of studies reviewed predominantly focusing on approaches dealing with quality of service, artificial intelligence and machine learning, and the use of signal strength, there is room for further optimization and integration. Approaches such as clustering and zoning, and caching mechanisms have been least studied yet they possess the potential to improve routing and consequently network performance, and therefore could be investigated in future research to explore their potential.

RQ2. The second research question was reviewing the limitations of approaches employed in extending AODV for performance improvement in MANET. The limitations revealed in the study for every approach were documented in Table 3, with the corresponding references. One of the key limitations of the approaches is routing overheads, thus the approaches can be optimized to reduce redundant route messages rebroadcasts and cause improved network performance.

RQ3. The third research question was reviewing the characteristics of AODV that are extended for performance improvement in MANET. The study revealed that the common characteristics of AODV protocol that are extended are route discovery, route selection, route maintenance, and time to live as shown in Table 4. Route discovery had 57% of studies addressing it, route selection was addressed by 20% of the studies, route discovery, and selection treated as a unit had 16% of studies addressing them, while route maintenance had 5% of studies addressing it. The study reveals that significant efforts to enhance AODV and thus consequently improve its performance in MANET, were focused primarily on the extension of AODV route discovery characteristic. This could be because significant control traffic in the network which impacts performance is generated during AODV route discovery, and therefore further research is warranted in this area.

5. CONCLUSION AND FUTURE WORK

This paper has uncovered approaches in literature employed in extending or modifying AODV protocol to optimize performance in MANET, and the approaches limitations. Further, the study revealed the AODV routing protocol characteristic commonly extended or modified for performance improvement in MANET. Fourteen (14) approaches were identified from the eighty-three (83) studies reviewed. The top three approaches employed were consideration of parameters to improve Quality of Service (QoS) with twenty (20) studies, artificial intelligence and machine learning with twenty (20) studies, and considering signal strength with nine (9) studies. Despite the approaches extending the AODV protocol to guarantee performance improvement in MANETs, there is more room for optimization and integration. Approaches such as clustering and zoning, and caching mechanisms have been least studied yet they possess the potential to improve routing and consequently network performance, and therefore could be investigated in future research to explore their potential. Therefore, the study recommends that future work could investigate clustering and zoning, and caching mechanisms approaches.

REFERENCES

[1] R. Samurathi and V. Jayalakshmi, "Study of Clustering Schemes in Mobile Ad hoc Networks," in *Proceedings of the Sixth International Conference on Intelligent Computing and Control Systems (ICICCS 2022). IEEE Xplore Part Number: CFP22K74-ART; ISBN: 978-1-6654-1035-9,* 2022.

[2] S. A. Ajagbe, M. O. Ayegboyin, I. R. Idowu, T. A. Adeleke and D. N. H. Thanh, "Investigating Energy Efficiency of Mobile Ad-hoc Network Routing Protocols," *Informatica,* vol. 46, pp. 269-275, 2022.

[3] V. R. Verma, D. P. Sharma and C. S. Lamba, "Performance Improvement in MANET Routing by Paradigm shifting through Mobile Agent Approach," in *Proceedings of ICAEEC-2019*, IIIT Allahabad India, 2019.

[4] R. R. Sarkar and M. Z. Rahman, "TRANSMISSION POWER AND QUALITY OF SERVICE IN MANET ROUTING PROTOCOLS," *International Journal of Wireless & Mobile Networks (IJWMN),* vol. 14, no. 4, 2022.

[5] K. Y. Cett, N. A. Mahiddin and F. F. M. Affandi, "PERFORMANCE ANALYSIS OF OLSR PROTOCOL IN MANET CONSIDERING DIFFERENT MOBILITY SPEED AND NETWORK DENSITY," *International Journal of Wireless & Mobile Networks (IJWMN),* vol. 13, no. 6, 2021.

[6] K. Wane, N. Chopade and G. Rahate, "A Comprehensive Survey of Routing Techniques in MANETs," in *2nd International Conference on IoT Based Control Networks and Intelligent Systems(ICICNIS 2021)*, 2021.

[7] G. K. Siddesh, C. P. Mallikarjuna Gowda, H. R. Shashidhara, K. Sathish Shet, K. Shashi Raj, V. Arunarashmi, S. Chaithanya, B. N. Latha and D. M. Teressa, "Optimization in the Ad Hoc On-Demand Distance Vector Routing Protocol," *Wireless Communications and Mobile Computing,* vol. 2022, 2022.

[8] M. Ahmad, A. Hameed, A. A. Ikram and I. Wahid, "State-of-the-Art Clustering Schemes in Mobile Adhoc Networks:Objectives, Challenges and Future Directions," *IEEE Access,* vol. 7, pp. 17067-17081, 2019.

[9] L. N. Hung and V. K. Quy, "A Review: Performance Improvement Routing Protocols for MANETs," *Journal of Communication,* vol. 15, no. 5, 2020.

[10] A. B. Kumari and K. Rohini, "A Review on Security Issues and Gaps in the Literature in Mobile Adhoc Networks," *International Journal of Creative Research Thoughts (IJCRT),* vol. 6, no. 1, 2018.

[11] I. M. Talukdar, R. Hassan, S. M. Hossen, K. Ahmad, F. Qamar and A. S. Ahmed, "Performance Improvements of AODV by Black Hole Attack Detection Using IDS and Digital Signature," *Wireless Communications and Mobile Computing,* Vols. 2021 , Article ID 6693316, 2021.

[12] M. A. Al-Absi, A. A. Al-Absi, M. Sain and H. Lee, "Moving Ad Hoc Networks-A Comparative Study," *Sustainability|MDPI,* vol. 13, 2021.

[13] A. M. Eltahlawy, H. K. Aslan, E. G. Abdallah, M. S. Elsayed, A. D. Jurcut and M. A. Azer, "A Survey on Parameters Affecting MANET Performance," *Electronics | MDPI,* vol. 12, no. 1956, 2023.

[14] A. A. A. Saif and K. Kumar, "Enhance the performance of AODV routing protocol in mobile ad-hoc networks," in *4th International Conference on Intelligent Circuots and Systems*, 2022.

[15] V. Tilwari, K. Dimyati, M. N. Hindia, A. Fattouh and I. S. Amiri, "Mobility,Residual Energy, and Link Quality Aware Multipath Routing in MANETs with Q-Learning Algorithm," *Applied Sciences|MDPI,* vol. 9, no. 1582, 2019.

[16] A. H. Mohsin, "Optimize Routing Protocol Overheads in MANETS: Challenges and Solutions:A review Paper," *Wireless Personal Communications,* vol. 126, pp. 2871-2910, 2022.

[17] S. Peng, Y. Wang, H. Xiao and B. Lin, "Implementation of an Improved AODV Routing Protocol for Maritime Ad-hoc Networks," in *2020 13th International Congress on Image and Signal processing,BioMedical Engineering and Informatics*, 2020.

[18] S. Deepika, N. Nishanth and A. Mujeeb, "An Assessment of Recent Advances in AODV Routing Protocol Path Optimization Algorithms for Mobile Ad hoc Networks," in *2021 Fourth International Conference on Microelectronics, Signals & Systems(ICMSS)| 978-1-6654-4885-7/21*, 2021.

[19] M. S. Said, A. S. Volkov, V. S. Martynov and I. A. Zhuravlev, "Application of Clustering Methods in MANET," *IEEE,* 2020.

[20] A. A. Mahamune and M. M. Chandane, "Evaluating Routing Protocols for Mobile Ad Hoc Networks Under Varying Network Scenarios," in *Proceedings of the Third INternational Conference on INtelligent Communication Technologies and Virtual Mobile Networks*, 2021.

[21] F. Tabbana, "PERFORMANCE COMPARISON AND ANALYSIS OF PROACTIVE, REACTIVE AND HYBRID ROUTING PROTOCOLS FOR WIRELESS SENSOR NETWORKS,"*International Journal of Wireless & Mobile Networks (IJWMN),* vol. 12, no. 4, 2020.

[22] T. A. Teli, R. Yousuf and D. A. Khan, "MANET Routing Protocols, Attacks and Mitigation Techniques: A Review," *International Journal of Mechanical Engineering,* vol. 7, no. 2, 2022.

[23] N. Srivastava and S. Srivastava, "A Review on AODV Based Backup Routing Schemes in Mobile Ad Hoc Network," *International Journal of Advanced Research in Computer Science and Software Engineering,* vol. 7, no. 3, 2017.

[24] I. Alameri, J. Komarkova, T. Al-Hadhrami and A. Lofti, "Systematic review on modification to the ad-hoc ondemand distance vector routing discovery mechanics," *PeerJ Computer Science,* 2022.

[25] S. Tyagi, S. Som and Q. P. Rana, "Reliability Based Variant Of AODV In MANETs: Proposal ,Analysis and Comparison," in *7th International Conference on Communication, Computing and Virtualization 2016*, 2016.

[26] M. Arun and R. Jayanthi, "An adaptive congestion and energy aware multipath routing scheme for mobile ad-hoc networks through stable link prediction," *ELSEVIER,* 2023.

[27] N. Sakthipriya, "A Novel Approach for an Optimized Route Discovery and Packet Forwarding for Ad-hov Networks Using Multi Rate Routing Protocol," *Middle-East Journal of Scientific Research,* vol. 20, no. 11, pp. 1517-1523, 2014.

[28] K. Mahajan, M. A. Rizvi and S. Karaulia, "Path Optimization Of AODV By EO-AODV In MANET," *ACM Digital Library,* 2014.

[29] Y. M. Sharma, P. K. Saini and P. Kumar, "ORSM: An Optimized Routing Scheme for MANETs," in *Proceedings of the Second International Conference on Inventive Systems and Control (ICISC 2018)*, 2018.

[30] H. Padwad and S. V. Sonekar, "An Empirical Approach of Optimizing AODV Routing Protocol for Routr Discovery in Mobile Ad-Hoc Network," *International Journal of Computer Science and Information Technologies,* vol. 5, no. 3, pp. 4259-4264, 2014.

[31] S. K. Sharma and S. Sharma, "Improvement over AODV Considering QoS Support in Mobile Ad-hoc Networks," *International Journal of Computer Networks and Applications,* vol. 4, no. 2, 2017.

[32] H. Alani, M. Abdelhaq and R. Alsaqour, "Dynamic routing discovery scheme for high mobility in mobile ad hoc networks," *International Journal of Electrical and Computer Engineering,* vol. 10, no. 4, pp. 3702-3714, 2020.

[33] S. M. Khan, R. Nilavalan and a. F. Sallama, "A Novel Approach for Reliable Route Discovery in Mobile Ad-Hoc Network," *Wireless Pers Commun (2015),* pp. 1519-1529, 2015.

[34] K. Ragunathan and T. Kathiravelu, "A Hop-count and Time based MANET Routing Protocol," *IEEE,* 2016.

[35] S. A. Mostafa, A. Y. C. Tang, M. H. Hassan and S. H. Khaleefah, "A Multi-Agent Ad Hoc On-Demand Distance Vector for Improving the Quality of Service in MANETs," in *2018 International Symposium on Agent, MultiAgent Systems and Robotics (ISAMSR)*, 2018.

[36] L. Sharma and P. Dimri, "An Improved AODV with QoS Support in Mobile Ad-Hoc Network," *IEEE,* 2015.

[37] R. Kumar, "Bandwidth Estimation with Mobility Control in Mobile Ad Hoc Networks," in *Proceedings of the Seventh International Conference on Communication and Electronics Systems (ICCES 2022)*, 2022.

[38] E. Temesgen, A. O. Salau, E. Yitayal and S. L. Braide, "Efficient MANETs Routing Algorithm to Mitigate Latency Based on AODV," in *2023 International Conference On Cyber Management And Engineering (CyMaEn)*, 2023.

[39] L. U. Khan, S. A. Mahmud, M. H. Zafar, G. M. Khan and H. S. Al-Raweshidy, "M-AODV: Modified Ad Hoc On-demand Distance Vector Routing Scheme," in *2014 9th International Symposium on Communication Systems, Networks & Digital Sign (CSNDSP)*, 2014.

[40] P. Singh and H. Dhawan, "Node Mobility Based Route Selection in AODV for use in MANETs," in *2015 International Conference on Computing Communication Control and Automation*, 2015.

[41] R. Kumar and M. Gupta, "Route Stability and Energy Aware based AODV in MANET," *IEEE,* 2014.

[42] S. K. Mohapatra, S. R. Swain, S. K. Mahapatra and S. K. Behera, "Stability and Energy Aware Reverse AODV Routing Protocol in MANETs," in *2015 IEEE 2nd International Conference on Recent Trends in Information Systems (ReTIS)*, 2015.

[43] S. Gao, H. Li and Q. Zhang, "An Optimized Routing Protocol for MANETs Based on Multi-Metric Dynamic Weighting," in *2022 IEEE 5th International Conference on Electronics Technology (ICET)*, 2022.

[44] S. K. Srivastava and A. Agarwal, "Implementation of Ant Colony Optimization Algorithm for Load Balancing Routing in MANET Network," in *2022 Second International Conference on Advanced Technologies in Intelligent Control, Environment, Computing & Communication Engineering*, 2022.

[45] D. Sarkar, S. Choudhury and A. Majumder, "Enhanced-Ant-AODV for optimal route selection in mobile ad-hoc network," *Journal of King Saud University - Cmputer and Information Sciences,* vol. 33, no. 2021, pp. 11861201, 2018.

[46] H. Kadhim and M. A. Hatem, "Modification AODV Routing Protocol to Find Best Shortest Path Based on Parallel Modified ACO-DNN," in *2nd International Conference on Engineering Technology and their Applications 2019-IICET2019*, 2019.

[47] M. Kaur and V. Chopra, "Rank Based ACO Approach for AOMDV with Load Balancing in Ad hoc Network," in *Proceedings of International Interdisciplinary Conference On Engineering Science & Management*, India, 2016.

[48] S. K. Khatri and M. Dixit, "Reducing Route Discovery Latency in MANETs Using ACO," *IEEE*, 2015.

[49] V. Duraisamy and V. Balaji, "Ant Optimized Link Quality for Ad Hoc on Demand Distance Vector," *Wireless Pers Commun,* vol. 79, no. 2014 . DOI 10.1007/s11277-014-1885-x, pp. 763-771, 2014.

[50] B. Nancharaiah and B. C. Mohan, "Modified Ant Colony Optimization to Enhance," in *2014 2nd International Conference on Business and Infonnation Management (lCBIM)*, 2014.

[51] G. Singh, N. Kumar and A. K. Verma, "ANTALG:An Innovative ACO based Routing Algorithm for MANETs," *Journal of Network and Computer Applications,* vol. 45, no. 2014, pp. 151-167, 2014.

[52] S. Ahmadzadeh and B. Bokharaeian, "A Heuristic-based Approach for Improvement the Performance of Probabilistic AODV Routing Algorithms in MANETs," in *2022 8th Iranian Conference on Signal Processing and Intelligent Systems (ICSPIS)*, Mazandaran, Iran, 2022.

[53] J. Agrawal, A. Singhal and R. N. Yadav, "Multipath Routing in Mobile Ad-hoc Network using Meta-heuristic Approach," *IEEE,* 2017.

[54] J. Kaur and G. Singh, "Hybrid AODV Algorithm for Path Establishment in MANET using Bio Inspired Techniques," in *IEEE International Conference on Power, Control, Signals and Instrumentation Engineering (ICPCSI-2017)*, 2017.

[55] V. Trivedi, P. Nayak, D. G. Padhan and N. Mohan, "Performance Enhancement of AODV Routing Protocol for MANET Using Genetic Algorithm," in *Proceedings of the Second International Conference on Electronics and Sustainable Communication Systems*, 2021.

[56] A. Moghaddam and A. Payandeh, "A Secure and Efficient Routing Protocol with Genetic Algorithm in Mobile Ad-hoc Networks," *ACSIJ Advances in Computer Science: an International Journal,* vol. 4, no. 6, 2015.

[57] A. Biradar and R. C. Thool, "Reliable Genetic Algorithm Based Intelligent Routing for MANET," *IEEE,* 2014.

[58] F. Safari, H. Kunze, J. Ernst and D. Gillis, "A Novel Cross-Layer Adaptive Fuzzy-Based Ad Hoc On-Demand Distance Vector Routing Protocol for MANETs," *IEEE,* 2023.

[59] N. I. Abbas and M. Ilkan, "Fuzzy approach to improving route stability of the AODV routing protocol," *EURASIP Journal on Wireless Communications and Networking,* 2015.

[60] K. N. Raju, A. Sirisha, U. Nanaji, S. K. Sharma and C. R. Kumar, "An adaptive hello interval for AODV through ANFIS to improve the performance of MANETs," *International Journal of Knowledge-based and Intelligent Engineering Systems,* vol. 25, no. 2021, pp. 235-242, 2021.

[61] L. H. Binh and T.-V. T. Duong, "An improved method of AODV routing protocol using reinforcement learning for ensuring QoS in 5G-based mobile ad-hoc networks," *ICT EXpress,* vol. 10, no. 2024, pp. 97-103, 2023.

[62] M. H. Hassan, S. A. Mostafa, M. A. Mohammed, D. A. Ibrahim, B. A. Khalaf and A. S. Al-Khaleefa, "INTEGRATING AFRICAN BUFFALO OPTIMIZATION ALGORITHM IN AODV ROUTING PROTOCOL FOR IMPROVING THE QOS OF MANET," *JOURNAL OF SOUTHWEST JIAOTONG UNIVERSITY,* vol. 54, no. 3, 2019.

[63] K. M. Omran, "The Routing Control in Mobile Ad hoc Network Using Intelligent Optimization Algorithms," *IEEE,* 2020.

[64] S. Maamar and B. Abderezzak, "Predict Link Failure in AODV Protocol to provide Quality of Service in MANET," *I. J. Computer Network and Information Security,* vol. 2016, pp. 1-9, 2016.

[65] P. Gite, "Link Stability Prediction for Mobile Ad-hoc Network Route Stability," in *International Conference on Inventive Systems and Control(ICISC-2017)*, 2017.

[66] N. P. Modi and K. J. Panchal, "Improving AODV Protocol Through Cross Layer Design in MANET," *International Journal for Scientific Research & Development*, vol. 3, no. 3, 2015.

[67] A. Yadav, Y. N. Singh and R. R. Singh, "Improving Routing Performance in AODV with Link Prediction in Mobile Adhoc Networks," *Wireless Pers Commun*, vol. 83, pp. 603-618, 2015.

[68] N. Nissar, N. Naja and A. Jamali, "A Neighbor Signal Strength based Coverage for Reducing Ruoting Overhead in Mobile Ad Hoc Networks," *IEEE*, 2016.

[69] V. Sharma and R. Nagpal, "Enhanced AODV Protocol for Quality Services," *International Journal of Computer Science & Management Studies*, vol. 14, no. 1, 2014.

[70] M. Khan, D. S. M and S. A. D, "Cross Layer Design Approach for Congestion Control in MANETs," in *2016 IEEE International Conference on Advances in Electronics, Communication and Computer Technology (ICAECCT)*, Pune India, 2016.

[71] C. Dhakad and A. S. Bisen, "Efficient Route Selection By Using Link Failure Factor In MANET," in *International Conference on Electrical, Electronics, and Optimization Techniques (ICEEOT) - 2016*, 2016.

[72] P. Shete and R. N. Awale, "Channel Quality Based Adaptive Gossip Flooding Mechanism for AODV," in *The 2015 4th International Workshop on Physics-Inspired Paradigms in Wireless Communications and Networks*, 2015.

[73] E. Zamani and M. Soltanaghael, "The Improved Overhearing Backup AODV Protocol in MANET," *Journal of Computer Networks and Communications*, vol. 2016, 2016.

[74] T. Chowdhury and R. B. M. Mukta, "A Novel Approach to Find the Complete Node-Disjoint Multipath in AODV," in *3rd INTERNATIONAL CONFERENCE ON INFORMATICS, ELECTRONICS & VISION 2014*, 2014. [75] M.-Y. Su and C.-W. Yang, "A Resilient Routing Approach for Mobile Ad Hoc Networks," *IEEE*, 2015.

[76] S. S and G. Geetha, "AODV Based Backup Routing for Optimized Performance in mobile Ad-hoc Networks," in *Proceedings of the IEEE 2017 International Conference on Computing Methodologies and Communication(ICCMC)*, 2017.

[77] S. Biradar and P. Kulkarni, "Enhancing the Quality of Service using M-AODV Protocol in MANETs," *IEEE*, 2015.

[78] Rao Meena, M. Rao and N. Singh, "Quality of Service Enhancement in MANETs with an Efficient Routing Algorithm," *IEEE*, 2014.

[79] N. Kaur and R. Singhai, "Analysis of Traffic Impact on Proposed Congestion Control Scheme in AODV," *Wireless Personal Communications (2019)*, vol. 109, p. 1395–1418, 2019.

[80] Y. Mai, F. M. Rodriguez and N. Wang, "CC-ADOV: An Effective Multiple Paths Congestion Control AODV," *IEEE*, 2018.

[81] B. Bansal, M. R. Tripathy, D. Goyal and M. Goyal, "Improved Routing Protocol for MANET," in *2015 Fifth International Conference on Advanced Computing & Communication Technologies*, 2015.

[82] P. Ranjan and R. L. Velusamy, "Optimized Local Route Repair and Congestion Control in Mobile Ad hoc Network," *IEEE*, 2015.

[83] M. K. Gulati and K. Kumar, "Stable Energy efficient QoS based Congestion and DElay aware Routing (SEQCDR) Protocol for MANETs," in *IEEE ICCSP 2015 conference*, 2015.

[84] A. Guidoum, S. Achour and M. Tayeb, "Enhancing performance AODV routing protocol to avoid congestion," in *2022 6th European Conference on Electrical Engineering & Computer Science (ELECS)*, 2022.

[85] C. Mafirabadza, T. T. T. Makausi and P. Khatri, "Efficient Power Aware AODV Routing Protocol in MANET," *ACM*, 2016.

[86] G. Singh, A. K. Sharma and O. S. Bawa, "Energy - Optimized Route Discovery in AODV," in *2019 International Conference on Automation, Computational and Technology Management (ICACTM)*, 2019.

[87] S. Mehfuz and S. Kumar, "Energy Aware Probabilistic Broadcasting for Mobile Adhoc Network," *IEEE*, 2015.

[88] N. Ket and S. Hippargi, "Modified AODV Energy Aware Routing for Optimized Performance in Mobile Ad-hoc Networks," in *IEEE WiSPNET 2016 conference*, 2016.

[89] M. M. D. J. T. Hansika and J. J. A. D. Anuradha, "Guaranteeing Quality of Service and Low Power Consumption in Mobile Ad-Hoc Networks," in *2014 International Conference on Advances in ICT for Emerging Regions(ICTer):247-251*, 2014.

[90] A. Swidan, H. B. Abdelghany, R. Saifan and Z. Zilic, "Mobility and Direction Aware Ad-hoc On Demand Distance Vector routing protocol," in *The 13th International Conference on Mobile Systems and Pervasive Computing*, 2016.

[91] G. Soni and M. K. Jhariya, "Quadrant Base Location Tracking Technique in MANET," *IEEE*, 2020.

[92] S. Gupta and A. Mathur, "Enhanced Flooding Scheme for AODV Routing Protocol in Mobile Ad hoc Networks," in *2014 International Conference on Electronic Systems, Signal Processing and Computing Technologies*, 2014.

[93] A. Touzene and I. Al-Yahyai, "Performance Analysis of a Grid Based Route Discovery in AODV Routing Algorithm for MANET," in *2014 Second International Conference on Artificial Intelligence, Modelling and Simulation*, 2014.

[94] V.-H. Nguyen, V. H. Nam, D. M. Linh and V. K. Quy, "An Improved Agent-Based AODV Routing Protocol for MANET," *EAI Endorsed Transactions on Industrial Networks and Intelligent Systems*, vol. 8, no. 27/e4, 2021.

[95] A. K. Bairwa and S. Joshi, "An agent based routing search methodology for improving QoS in MANET," *Ingeniare. Revista chilena de ingeniería*, vol. 28, no. 4, 2020.

[96] M. Rath and M. R. Panda, "MAQ System Development in Mobile Ad-hoc Networks Using Mobile Agents," *IEEE*, 2016.

[97] H. G. Yirga, G. D. Taye and H. M. Melaku, "An Optimized and Energy-Efficient Ad-Hoc On-Demand Distance Vector Routing Protocol Based on Dynamic Forwarding Probability (AODVI)," *Journal of Computer Networks and Communications*, 2022.

[98] N. Nissar, N. Naja and A. Jamali, "A review and a new approach to reduce routing overhead in MANETs," *Wireless Netw (2015)*, pp. 1119-1139, 2015.

[99] H. Y. Adarbah, S. Ahmad, B. Arefah and A. Duffy, "Efficient Broadcasting for Route Discovery in Mobile Adhoc Networks," *IEEE*, 2015.

[100] N. Phate, M. Saxena and M. A. Rizvi, "Minimizing Congestion and Improved QoS of AODV using Clustering in Mobile Ad Hoc Network," in *IEEE International Conference on Recent Advances and Innovations in Engineering (ICRAIE)*, Jaipur, India, 2014.

[101] I. M. A. Wikantyasa, T. Ahmad and R. M. Ijtihadie, "Centralized Control Approach in Managing Zone Based Routing to Improve MANET Performance," in *2024 10th International Conference on Smart Computing and Communication (ICSCC)*, 2024.

[102] B. B. Sagar and S. P. Singh, "MANET Performance Estimation Using Manhattan distance approach," in *2014 Sixth International Conference on Computational Intelligence and Communication Networks*, 2014.

[103] S. Sawwashere and A. Lanjewar, "Improved Cost Efficient AODV Routing Protocol," *International Journal of Engineering Research and General Science*, vol. 3, no. 2, 2015.

[104] H. Jhajj, R. Datla and N. Wang, "Design and Implementation of An Efficient Multipath AODV Routing Algorithm for MANETs," *IEEE*, 2019.

[105] S. H. Monga and E. S. Soni, "AODV BASED BACKUP NODE MECHANISM WITH QOS ENABLE ROUTING IN MOBILE AD-HOC NETWORKS," *THE ANNALS OF "DUNAREA DE JOS" UNIVERSITY OF GALATI,* vol. 40, no. 2, 2017.

[106] J. K. Thamalaka, T. R. J. S. Dasa, M. A. D. A. Weerasinge, H. D. K. M. Jayalal, N. Kuruwitaarachi and L. Rupasinghe, "Novel Caching Mechanism to Improve Performance in Mobile Ad-hoc Networks(MANETs)," *IEEE*, 2018.

AUTHORS

Patrick Macharia Njoroge is a seasoned Information Technologist and a Certified Information Systems Auditor. He holds a Bachelor of Science degree in Computer Science & Engineering from Maseno University conferred in 2002, and a Master's degree in Information Systems from Kisii University in 2020. Currently, he is pursuing a doctoral degree in Information Technology at Murang'a University of Technology, Kenya. His research interests lie in Computer Networks and Security; Artificial Intelligence and Data Mining. He is a member of the Information Systems Audit and Control Association (ISACA) and the International Association of Engineers (IAENG).

John Gichuki Ndia, is a Senior Lecturer in the Department of Information Technology and he is currently the Dean School of Computing and Information Technology, Murang'a University of Technology, Kenya. He holds a Bachelor of Information Technology degree from Busoga University conferred in 2009, and his MSc. in Data Communications from KCA University in 2013. He earned his PhD in Information Technology from Masinde Muliro University of Science and Technology in 2020. His research interests are in Software Quality, Artificial Intelligence Applications in S oftware Engineering, Computer Network Protocols, and Computer Networks Security. He is a member of the Institute of Electrical and Electronics Engineers (IEEE) and the Association for Computing Machinery (ACM)

Peter Maina Mwangiis a Tutorial Fellow at the Department of Computer Science, Murang'a University of Technology, Kenya. He received his BSc. in Computer Science from Busoga University, Uganda in 2010, his MSc in Data Communication and Networks from KCA University, Kenya in 2018 and his PhD in Computer Science from Murang'a University of Technology, Kenya in 2024. His research interest is in Computer Networks, Security, and Artificial Intelligence. He is a Professional Member of Institute of Electrical and Electronics Engineers (IEEE), the International Association of Engineers (IAENG) and Scientific & Technical Research Association (STRA).