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Ranking AODV Routing Characteristics in MANETs: Fuzzy Delphi Method Application

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Abstract
Optimization of Mobile Ad hoc Networks (MANET) routing has the potential to improve performance. Enhancing the Ad-hoc On-demand Distance Vector (AODV) protocol, which is predominantly used in MANET routing, would lead to performance improvements. This study sought to provide a structured approach to identifying which AODV protocol characteristics should be prioritized for modification to improve performance in MANETs. This would provide guidance for future research on AODV prioritization. Thirteen AODV characteristics were identified through a systematic review. The Fuzzy Delphi Method was employed to analyze and prioritize the study characteristics. Route discovery characteristics were prioritized and ranked as number one, with a threshold value of 0.097, 100% agreement among experts, and a fuzzy score of 0.72. The experts unanimously agreed that modifying the route discovery characteristic has the greatest potential to improve performance in MANET. This was because a large amount of control traffic in the network is generated during the route discovery process. The other characteristics were route selection, route maintenance, route table management, routing updates, number of routes discovered, hop count, time to live, and use of hello messages. However, some characteristics were perceived to be structurally critical for AODV operation but less responsive to performance-optimization modifications, namely hop-by-hop communication, identification of route request messages, sequence numbers, and neighbor lists. Future studies should complement the expert-based prioritization of AODV characteristics with experimental and simulation evaluations to quantify performance gains.

Keywords: *AODV Characteristics, Fuzzy Delphi Method, MANET, Performance Improvement, Prioritization.*

I. INTRODUCTION

The popularity of Mobile Ad-hoc Network (MANET) has gained traction over time when compared to the traditional wireless networks because of their distinctive features such as ease of deployment, dynamic topology, infrastructure-less, self-configuration, hop-by-hop communications and open network boundary (Kumari & Rohini, 2018; Wane, Chopade, & Rahate, 2021). Currently, MANET has found application in disaster management, battlefield communications by the military, smart homes, law enforcement, healthcare, robotics, agriculture, smart cities, virtual navigation, road safety, telemedicine, mobile conferencing, search and rescue operations (Anter et al., 2021; Blasco-Blasco et al., 2025; Deepika, Nishanth, & Mujeeb, 2021; Eltahlawy et al., 2023; Siddesh et al., 2022; Samurathi & Jayalakshmi, 2022).

In MANET primarily, routing governs the transmission delays for routes, energy consumption within the network, optimal routing path and volume of traffic. The performance of MANET is

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heavily dependent on the routing protocols (Hung & Quy, 2020), hence the need for an efficient routing protocol to manage the MANET (Priyambodo, Wijayanto, & Gitakarma, 2021), with low overheads. Prior scholarly works have identified Ad-hoc On-demand Distance Vector (AODV) protocol, as one of the predominantly utilized routing protocol (Kumari & Rohini, 2018; Peng, Wang, Xiao, & Lin, 2020; Naghipour, Rahim, & Iqbal, 2024; Njoroge, Ndia, & Mwangi, 2025) since it shuns loops in routing and minimizes route broadcasts (Teli, Yousuf, & Khan, 2022). A comparison of AODV protocol with other reactive protocols namely Dynamic Source Routing (DSR) and Temporally Ordered Routing Algorithm (TORA) shows that AODV protocol adapts with ease to the changing network topology and it’s very scalable (Tilwari, Dimyati, Hindia, Fattouh, & Amiri, 2019).

Evidence from literature depicts proposed improvements on AODV protocol with numerous studies focusing on improvements based on specific AODV characteristics modifications. Such optimized AODV variants are evaluated using performance metrics which include throughput, routing overheads, end-to-end delays, packet loss, and packet delivery ratio and energy efficiency (Deepika et al., 2021; Siddesh et al., 2022; Eltahlawy et al., 2023). However, these studies do not provide a structured approach for identifying which protocol characteristics are to be prioritized for modification to cause performance improvement in MANET. Subsequently, modification efforts tend to be disjointed across the different protocol aspects.

To address this gap, this study sought to contribute to the body of knowledge in MANET routing by presenting a systematic prioritization of AODV characteristics with potential to cause performance improvement when modified. The ranking or prioritization was done based on experts’ consensus, hence offering a tactical roadmap for future optimization research in MANET routing. Fuzzy Delphi Method (FDM) was applied to obtain experts consensus on identified AODV characteristics. The AODV characteristics were identified through a systematic review based on Barbara Kitchenham guidelines (Njoroge, Ndia & Mwangi, 2025). Table 1 displays the AODV characteristics with their impact on network performance.

Table 1. AODV Characteristics and Network Performance

Characteristic/Feature	Impact on Network Performance
Route Discovery	• Discovers a valid route from source node to destination • Redundant broadcast of Route Request (RREQ) messages creates extra control traffic in the network. This can consume the limited network bandwidth leading to decreased throughput, delays, packet loss and congestion. (Saif & Kumar, 2022; Ahmadzadeh & Bokharaeian, 2022; Deepika, Nishanth, & Mujeeb, 2021; Raju, Sirisha, Nanaji, Sharma, & Kumar, 2021)
Route Maintenance	• Causes repair of failed routes. • Frequent route breakages can cause creation of extra route error (RERR) messages and hence extra RREQ traffic as new routes are rediscovered, thus decreased throughput and increased end-to-end delays (Saif &

	Kumar, 2022; Raju, Sirisha, Nanaji, Sharma, & Kumar, 2021; Arun & Jayanthi, 2023; Rathod, Gumaste, & Bagadi, 2024)
Route Table Management	• Preserves routing information necessary for communication and data transmission. (Ahmadzadeh & Bokharaeian, 2022; Alameri, Komarkova, Al-Hadhrami, & Lofti, 2022; Guidoum, Achour, & Tayeb, 2022; Salroo & Sharma, 2023)
Route Selection	• Allows selection of most recent and shortest route for transmission of data thus ensuring reduced packet loss and increased throughput and packet delivery ratio. (Nguyen, Nam, Linh, & Quy, 2021; Guidoum, Achour, & Tayeb, 2022; Wang, Zhang, Zhang, Zhao, & Wei, 2022)
Sequence Numbers	• Improves performance by ensuring that only the freshest routes are available for data transmission. This eliminates loops in routing. (Siddesh, et al., 2022; Yirga, Taye, & Melaku, 2022)
Number of routes discovered	• When active route fails, and there exists no secondary route for data transmission, packet loss can occur. (Bairwa & Joshi, 2020; Ahmadzadeh & Bokharaeian, 2022; Kanellopoulos & Sharma, 2020)
Routing Updates	• Protocol has no routing updates, thus bandwidth is conserved for data transmission, and risk of packet loss and congestion is diminished. (Deepika, Nishanth, & Mujeeb, 2021; Safari, Kunze, Ernst, & Gillis, 2023; Santana, et al., 2023)
Use of hello messages	• Helps in Identification of neighbor nodes/Link Status and in detection of link failures. Vast hello message traffic can cause consumption of limited bandwidth, leading to delays and packet loss in the network. (Saif & Kumar, 2022; Deepika, Nishanth, & Mujeeb, 2021; Guidoum, Achour, & Tayeb, 2022)
Time to live (TTL) Value	• RREQ messages with valid TTL are recirculated in the network. Timed out RREQ messages are dropped. (Alani, Abdelhaq, & Alsaqour, 2020; Alameri, Komarkova, Al-Hadhrami, & Lofti, 2022; Guidoum, Achour, & Tayeb, 2022)
Identification of RREQ Messages	• This aids in detecting duplicate RREQ messages in the network. RREQ duplicates are dropped. (Alameri, Komarkova, Al-Hadhrami, & Lofti, 2022; Guidoum, Achour, & Tayeb, 2022; Wang, Zhang, Zhang, Zhao, & Wei, 2022)
Hop-by-hop communication	• No storage of the whole source path in the packet under transmission but only the address of the next hop neighbor node. (Ahmadzadeh & Bokharaeian, 2022; Alameri, Komarkova, Al-Hadhrami, & Lofti, 2022; Santana, et al., 2023; Salroo & Sharma, 2023)
Neighbor list	• Allows for identification of neighbors and routes associated with them. When a route failure occurs, RERR messages are sent to neighbors and invalid routes marked or removed. (Trivedi, Nayak, Padhan, & Mohan, 2021; Guidoum, Achour, & Tayeb, 2022)
Hop Count	• The route with the least hop count is selected for data transmission. (Nguyen, Nam, Linh, & Quy, 2021; Deepika, Nishanth, & Mujeeb, 2021; Arun & Jayanthi, 2023)

This paper is structured as follows: Literature review is discussed in section two, while research method is presented in section three, section four focusses on the study findings while section five presents the discussion, and section six presents the study conclusion and recommendation.

II. RELATED WORKS

The authors (Naghipour, Rahim, & Iqbal, 2024), employed Fuzzy Delphi Method in development of a 5G competency model, which identifies, assesses, and introduces the requisite knowledge, competencies and attributes for effective performance in any job assignment related to 5G in the industrial environment. This was useful in guiding the hiring, the training and development within the environment. Further, (Rahayu & Wulandari, 2021) utilized Fuzzy Delphi Method to assist in identification and prioritization of both internal and external factors which can be applied in development of e-portfolio systems design. Moreover, (Yusof, Hashim, & Hussain, 2022) explored the use of Fuzzy Delphi Method in human-computer interaction studies.

The authors (Rejeb, Rejeb, Keogh, & Zailani, 2022), applied Fuzzy Delphi Method integrated with Best-Worst Approach to analyze and rank the barriers to adoption of blockchain in the circular economy. Further, (Yaccob, Yunus, & Hashim, 2024) utilized Fuzzy Delphi Method, to obtain experts consensus pertaining the indicators which can be used to represent the constructs in a knowledge domain, which are essential in the development of an English as Second Language(ESL) Global Competence Framework.

III. RESEARCH METHOD

The study utilized Fuzzy Delphi Method to analyze and obtain the experts consensus (Hasim et al., 2023) and systematic prioritization of the AODV characteristics. The Fuzzy Delphi Method is a hybrid of the Delphi method and the Fuzzy theory (Yusof, Hashim, & Hussain, 2022), and this provides for conversion of linguistic expert judgements into quantifiable fuzzy numbers, thus minimizing ambiguity and enabling structured consensus formation as depicted in Table 5. The Fuzzy Delphi Method has several advantages over traditional Delphi method as it allows for gathering of expert opinions in a single phase, thus avoiding numerous rounds to attain coherence, and the process is simplified, therefore causing a reduction in execution time and costs (Blasco-Blasco et al., 2025). Further, Fuzzy Delphi Method ensures validity and corroborates items through opinion and consensus of experts.

In literature, numerous studies have evaluated AODV performance based on metrics, which focusses on specific protocol characteristic modifications (Deepika et al., 2021; Siddesh et al., 2022; Eltahlawy et al., 2023). The literature therefore provides disjointed insights concerning which protocol characteristics have the greatest potential to cause performance improvement when modified. Consequently, Fuzzy Delphi Method was adopted to provide the structured expert consensus and systematic prioritization of AODV protocol characteristics, before simulation experiments are attempted. Through aggregation of judgements of practitioners and researchers, FDM assisted in systematic prioritization of protocol characteristics in terms of their potential to cause performance improvement in future implementation or simulation studies.

The study population consisted of experts in computer networking in Kenya, drawn from both academia and industry. The experts were holders of varying academic qualifications namely diploma, degree, masters or doctoral degree in Computer Science, Information Technology or related courses. To ensure the credibility of the experts, an inclusion criterion was applied whereby the experts were expected to have moderate level of knowledge about MANET and possess working experience of 6 years and above for their opinion to be considered in the study analysis.

The experts were identified through purposive sampling. This assisted in selection of respondents who had requisite knowledge and skills in the domain of study. The authors (Yusof, Hashim, & Hussain, 2022), highlights that the acceptable number of experts involved in the study can range from a minimum of ten (10) up to fifty(50), while (Khaira & Ibrahim, 2024) states that the minimum number of experts to be involved in Fuzzy Delphi Method to be 10. A sample size of 40 experts was deemed sufficient for use in the study. However, out of the forty respondents, one respondent had low level of knowledge about MANET, thus excluded from the final Fuzzy Delphi Method analysis and reporting.

The survey data was collected using an online questionnaire which consisted of proposed AODV characteristics that could be extended to cause performance improvement in MANET, and the experts were to indicate their level of agreement against each of the characteristic. The extent of expert's level of agreement was rated using a 5-point Likert scale whereby strongly Agree = 5, Agree =4, Neutral=3, Disagree=2 and Strongly Disagree =1. The survey link for the google form was shared with the experts via their email addresses. The researcher carried out a pilot study with five experts to assist in removing any ambiguity in the questions and guarantee the quality of the data to be collected. The Cronbach Alpha was calculated and found to be 0.732, indicating an acceptable internal consistency reliability and thus the data collection tool was deemed reliable for the study. A value of 0.7 and above is considered satisfactory reliability (Khatri, Shukla, Thomas, Shiva, & Behl, 2025). The feedback received from the pilot phase further allowed the researcher to refine any item in the questionnaire which was ambiguous, hence improving on the content validity of the data collection tool.

The researcher addressed potential bias in expert perception by ensuring that the respondents were drawn from both industry and academics, thus allowing for diversity of perspectives. Further, the responses were gathered anonymously via an online questionnaire thus increasing the possibility of accuracy and objectivity in the responses. Moreover, FDM mathematically aggregates experts' opinion, minimizing the influence of extreme individual opinions and thus availing a balanced consensus. As per the experts' inclusion criteria, the study considered responses from thirty-nine experts amounting to 97.5% response rate, thus the non-response bias was deemed minimal.

IV. FINDINGS

A. Demographic Information of the Study

The study had forty expert respondents whereby five were PhD holders, nineteen were master's holders, fifteen were degree holders while one was a diploma holder. This implied that the experts had the requisite education to understand and competently respond to the questions in the study as indicated in Table 2.

Table 2. Educational Level of Experts

Educational Level	Frequency	Percentage (%)
PhD	5	12
Masters	19	48
Degree	15	38
Diploma	1	2
Total	**40**	**100**

Further, in terms of working experience in the field of computer networks, twenty-two experts had working experience of 11 years and above, seventeen experts had a working experience of between 6 and 10 years, while one expert had a working experience of between 3 and 5 years. This was a clear indication that the experts had sufficient working experience in the domain of study as depicted in Table 3. However, the threshold experience of experts in the study was 6 years and above, hence one expert whose working experience was between 3 to 5 years was excluded from the final analysis of the study.

Table 3. Working Experience of Experts in Computer Networks

Working Experience	Frequency	Percentage (%)
11 Years and Above	22	55%
6 to 10 Years	17	43%
3 to 5 Years	1	2%
Up to 2 Years	0	0%
Total	**40**	**100%**

Moreover, in terms of expert's level of knowledge in MANET, eight experts had their level rated as very high, twenty-one had their level rated as high, ten had their level rated as moderate while one expert had the level rated low. The threshold for the level of knowledge for the experts in the study was moderate and above, hence one expert whose knowledge was rated as low was excluded from the final analysis of the study. This is shown in Table 4.

Table 4. Experts Level of Knowledge

Level	Frequency	Percentage (%)
Very High	8	20%
High	21	53%
Moderate	10	25%
Low	1	2%
Total	**40**	**100%**

B. Analysis of Experts Opinion using Fuzzy Delphi Method

The first step was to convert the Likert scale responses to triangular fuzzy numbers. The study adopted the conversion of the linguistic expressions into the fuzzy numbers as in study (Oteng, Zuo, & Sharifi, 2022; Anter et al., 2021) modified as indicated in Table 5. In Table 5, *n1* represents the minimum fuzzy value*, n2* represents the middle fuzzy value while *n3* depicts the maximum fuzzy value. For example, an expert who gave a Likert scale response of 5 for an item, would have the same replaced using 0.6, 0.8 and 1.0 triangular fuzzy numbers.

Table 5. Triangular Fuzzy Numbers for Five-Point Likert Scale

Linguistic Expression	**Likert Scale Response**	**Triangular Fuzzy Numbers**		
		n1	*n2*	*n3*
Strongly Agree	5	0.6	0.8	1
Agree	4	0.4	0.6	0.8
Neutral	3	0.2	0.4	0.6
Disagree	2	0	0.2	0.4
Strongly Disagree	1	0	0	0.2

Further, the researcher keyed in the Likert scale values representing the expert's opinion responses into the item space for every item, then converted them into triangular fuzzy numbers as per Table 4. This process provided for a standardized method of inputting experts opinion responses into the Fuzzy Delphi Method framework (Yin & Hanif, 2024).

Furthermore, the average fuzzy values were calculated namely m1, m2, m3 from the fuzzy scale. The summation of fuzzy values for all n1,n2 and n3 for every expert per item is calculated separately, then each summation is divided by the number of experts to yield respective average fuzzy values namely m1, m2, and m3 which falls within a range of 0 to 1. Table 6 illustrates calculation of average fuzzy values for route discovery characteristic whose Likert scale responses were replaced with respective triangular fuzzy numbers.

Table 6. Calculation of Average Fuzzy Value

Expert	**n1**	**n2**	**n3**
Expert 1	0.6	0.8	1.0
Expert 2	0.6	0.8	1.0
Expert 3	0.4	0.6	0.8
Expert 4	0.6	0.8	1.0
Expert 5	0.6	0.8	1.0
Expert 6	0.6	0.8	1.0
Expert 7	0.6	0.8	1.0
Expert 8	0.4	0.6	0.8
Expert 9	0.6	0.8	1.0
Expert 10	0.4	0.6	0.8
Expert 11	0.4	0.6	0.8
Expert 12	0.4	0.6	0.8
Expert 13	0.6	0.8	1.0
Expert 14	0.4	0.6	0.8
Expert 15	0.4	0.6	0.8
Expert 16	0.4	0.6	0.8
Expert 17	0.6	0.8	1.0
Expert 18	0.6	0.8	1.0
Expert 19	0.4	0.6	0.8
Expert 20	0.6	0.8	1.0
Expert 21	0.6	0.8	1.0

Expert 22	0.6	0.8	1.0
Expert 23	0.6	0.8	1.0
Expert 24	0.6	0.8	1.0
Expert 25	0.6	0.8	1.0
Expert 26	0.6	0.8	1.0
Expert 27	0.4	0.6	0.8
Expert 28	0.4	0.6	0.8
Expert 29	0.6	0.8	1.0
Expert 30	0.4	0.6	0.8
Expert 31	0.6	0.8	1.0
Expert 32	0.4	0.6	0.8
Expert 33	0.6	0.8	1.0
Expert 34	0.6	0.8	1.0
Expert 35	0.6	0.8	1.0
Expert 36	0.4	0.6	0.8
Expert 37	0.6	0.8	1.0
Expert 38	0.4	0.6	0.8
Expert 39	0.4	0.6	0.8
Average (m)	**0.518**	**0.718**	**0.918**

Further, the threshold value, d, was calculated to determine whether an item would be accepted or rejected depending on the level of agreement among the experts (Yin & Hanif, 2024). The threshold value, d was calculated using the Formula (1) and as shown in Table 7 (Yusoff, et al., 2024; Anter et al., 2021).

$$d(\tilde{m},\tilde{n}) = \sqrt{\frac{1}{3}\left[(m_1-n_1)^2+(m_2-n_2)^2+(m_3-n_3)^2\right]} \tag{1}$$

Table 7 illustrates the calculation of the threshold value, d, for route discovery characteristic. The formula above (1) was utilized to calculate the threshold, d, for each and every expert and then an average threshold was calculated.

Table 7. Calculation of Threshold Value

Expert	Threshold (d)
Expert 1	0.082
Expert 2	0.082
Expert 3	0.118
Expert 4	0.082
Expert 5	0.082
Expert 6	0.082
Expert 7	0.082
Expert 8	0.118
Expert 9	0.082
Expert 10	0.118
Expert 11	0.118
Expert 12	0.118
Expert 13	0.082
Expert 14	0.118
Expert 15	0.118
Expert 16	0.118
Expert 17	0.082
Expert 18	0.082

Expert 19	0.118
Expert 20	0.082
Expert 21	0.082
Expert 22	0.082
Expert 23	0.082
Expert 24	0.082
Expert 25	0.082
Expert 26	0.082
Expert 27	0.118
Expert 28	0.118
Expert 29	0.082
Expert 30	0.118
Expert 31	0.082
Expert 32	0.118
Expert 33	0.082
Expert 34	0.082
Expert 35	0.082
Expert 36	0.118
Expert 37	0.082
Expert 38	0.118
Expert 39	0.118
Average Threshold (d)	**0.097**
d ≤ 0.2 (Count)	**39**
Consensus (%)	**100%**

Thereafter the average threshold value for each item was calculated and this was expected to be less than or equal to 0.2 (Yusoff, et al., 2024; Yusoff et al., 2021) (threshold value, (d) ≤ 0.2). Moreover, the expert's consensus for each and every item was calculated, which was expected to be equal to or greater than 75%. The count of the threshold values, d, for each item as calculated for every expert, threshold value (d) ≤ 0.2, expressed as a percentage should be equal to or greater than 75%. If this threshold was met the item was accepted or otherwise rejected.

The next step involved the defuzzification process (Naghipour, Rahim, & Iqbal, 2024), which is the calculation of the average fuzzy score (A), done using Formula (2).

$$A = \frac{1}{3} \times (m_1 + m_2 + m_3) \quad (2)$$

The defuzzification process, allows for the ranking of the items to determine their importance. The ranking is based on the calculated average fuzzy score(A), whose cut off is 0.5, to accept the item, otherwise the item is rejected (Yusoff, Hashim, Muhamad, & Hamat, 2021). The Fuzzy Delphi Method, allows the experts to reach a consensus on whether to accept or reject the items under consideration, after evaluating three pre-conditions (Yusoff, et al., 2024; Naghipour, Rahim, & Iqbal, 2024). Firstly, the threshold value, d for each item should be ≤ 0.2. Secondly, the threshold percentage agreement among experts per item should be ≥ 75%, and the last pre-condition is that the average fuzzy score (A) should be ≥ 0.5. The results of the Fuzzy Delphi Method analysis were presented in Table 8.

Table 8. Results of Fuzzy Delphi Method Analysis

No	**AODV Characteristic**	**Threshold Value,d ≤ 0.2**	**% Agreement among Experts (≥ 75%)**	**Average Fuzzy Numbers**			**Average Fuzzy Score(A), ≥ 0.5**	**Ranking**	**Experts Consensus**
				m1	**m2**	**m3**			
1	Route Discovery	0.097	100	0.518	0.718	0.918	0.72	1	ACCEPT
2	Route Maintenance	0.116	90	0.467	0.667	0.867	0.67	2	ACCEPT
3	Route Selection	0.118	92	0.472	0.672	0.872	0.67	2	ACCEPT
4	Route Table Management	0.103	92	0.456	0.656	0.856	0.66	3	ACCEPT
5	Routing Updates	0.126	79	0.410	0.610	0.810	0.61	4	ACCEPT
6	Number of routes discovered	0.133	95	0.400	0.600	0.800	0.60	5	ACCEPT
7	Hop Count	0.098	77	0.390	0.590	0.790	0.59	6	ACCEPT
8	Time to live(TTL)	0.113	77	0.379	0.579	0.779	0.58	7	ACCEPT
9	Use of Hello Messages	0.120	79	0.364	0.564	0.764	0.56	8	ACCEPT
The AODV characteristics below did not meet the FDM agreement threshold “ % Agreement among Experts (≥ 75%)”									
1	Neighbor List	0.091	**72**	0.395	0.595	0.795	0.59	-	***REJECT***
2	Sequence Number	0.149	**59**	0.390	0.579	0.779	0.58	-	***REJECT***
3	Identification of Route Request (RREQ)Messages	0.130	**69**	0.385	0.579	0.779	0.58	-	***REJECT***
4	Hop-by-hop Communication	0.145	**69**	0.349	0.549	0.749	0.55	-	***REJECT***

V. DISCUSSION

For any AODV characteristic to be accepted, it had to meet the three FDM preconditions namely, have a threshold value, d ≤ 0.2, secondly, have a threshold percentage agreement among experts been ≥ 75%, and the last pre-condition is that the average fuzzy score (A) should be ≥ 0.5. An AODV characteristic, meeting the three preconditions is considered accepted by the experts, otherwise rejected. The results of the expert’s consensus on the AODV protocol characteristics indicated that route discovery, route maintenance, route selection, route table management, routing updates, time to live (TTL), hop count, number of routes discovered and use of hello messages met the Fuzzy Delphi Method preconditions, hence accepted. This implies that the experts had considerable consensus about the nine (9) AODV characteristics that if they are extended they have the potential to cause performance improvement in MANET. In terms of the fuzzy scores, a higher value for a characteristic indicates a higher degree of perceived influence in causing significant impact on network performance. Route discovery had a fuzzy score of 0.72 while route maintenance and route selection each had a fuzzy score of 0.67. Therefore, route discovery characteristics were considered to have the most significant impact on network performance when optimized as compared to other AODV characteristics.

Route discovery emerged as the highest ranked AODV characteristic, with a threshold value, d of 0.097, 100% agreement among experts and fuzzy score of 0.72. The experts unanimously agreed that modification of the route discovery characteristic has the greatest potential to cause improvement. Route discovery process in AODV plays a critical role in finding a valid route from source node to destination, thus generating vast control traffic in the network. The rebroadcast of Route Request (RREQ) messages creates extra control traffic in the network, which can consume the limited network bandwidth leading to decreased throughput, delays, packet loss and congestion. (Saif & Kumar, 2022; Ahmadzadeh & Bokharaeian, 2022; Deepika, Nishanth, & Mujeeb, 2021; Raju, Sirisha, Nanaji, Sharma, & Kumar, 2021). Therefore, optimizing the route discovery process to reduce the routing overheads can significantly improve MANET performance hence increasing throughput, packet delivery ratio, and reducing delays, congestion and packet losses.

Route Maintenance and Route Selection were prioritized and ranked as number two. Route Selection allows selection of most recent and shortest route for transmission of data thus ensuring reduced packet loss and increased throughput and packet delivery ratio. (Nguyen, Nam, Linh, & Quy, 2021; Guidoum, Achour, & Tayeb, 2022; Wang, Zhang, Zhang, Zhao, & Wei, 2022). Route Maintenance is critical in AODV operation since it initiates repair of failed routes. Frequent route breakages can cause creation of extra route error (RERR) messages and hence extra RREQ traffic as new routes are rediscovered, thus decreased throughput and increased end-to-end delays (Saif & Kumar, 2022; Raju, Sirisha, Nanaji, Sharma, & Kumar, 2021; Arun & Jayanthi, 2023; Rathod, Gumaste, & Bagadi, 2024). Routing Table Management was ranked as number three, and routing table in AODV aids in preserving routing information necessary for communication and data transmission. (Ahmadzadeh & Bokharaeian, 2022; Alameri, Komarkova, Al-Hadhrami, & Lofti, 2022; Guidoum, Achour, & Tayeb, 2022; Salroo & Sharma, 2023). Therefore, optimization of routing table management can impact on routing efficiency and delivery times in the network. This can lead to increased throughput, reduced delays, minimized energy consumption and packet losses.

Further, Routing Updates was prioritized and ranked as number four. AODV discovers routes on demand, thus bandwidth is conserved for data transmission, and risk of packet loss and congestion is diminished. (Deepika, Nishanth, & Mujeeb, 2021; Safari, Kunze, Ernst, & Gillis, 2023; Santana, et al., 2023). Number of routes discovered was prioritized and ranked as number five. However, AODV by default returns one route after a route discovery process, therefore when the active route fails, and there exists no secondary route for data transmission, packet loss can occur. (Bairwa & Joshi, 2020; Ahmadzadeh & Bokharaeian, 2022; Kanellopoulos & Sharma, 2020). So modification of AODV protocol to preserve multiple routes discovered could be beneficial in preventing packet losses, decreasing delays and increasing throughput.

Moreover, Hop Count Characteristic was prioritized and ranked as number six. In AODV operation, the route with the least hop count is selected for data transmission. (Nguyen, Nam, Linh, & Quy, 2021; Deepika, Nishanth, & Mujeeb, 2021; Arun & Jayanthi, 2023). Therefore, optimization of this characteristic can impact throughput, packet loss and energy consumption within the network. Time to Live (TTL) characteristic was prioritized and ranked as number seven. Every RREQ created in AODV is assigned a TTL value, and RREQ messages with valid TTL are recirculated in the network, while timed out RREQ messages are dropped. (Alani, Abdelhaq, & Alsaqour, 2020; Alameri, Komarkova, Al-Hadhrami, & Lofti, 2022; Guidoum, Achour, & Tayeb, 2022). Optimization of this characteristic is critical in network performance affecting throughput, packet loss and routing overheads in the network. Use of Hello Messages was prioritized and ranked as number eight. Hello messages in AODV operation aids in identification of neighbor nodes and their link Status. A node which does not send hello messages to its neighbor nodes is considered to have gone offline. However, excessive hello messages can cause consumption of limited bandwidth, leading to delays and packet loss in the network. (Saif & Kumar, 2022; Deepika, Nishanth, & Mujeeb, 2021; Guidoum, Achour, & Tayeb, 2022).

However, the rejection of Hop-by-hop communication, Identification of route request messages, Sequence number and Neighbor list AODV characteristics does not mean that these characteristics are inconsequential in AODV operation. Rather, the experts' consensus suggests that these four characteristics have limited potential for optimization, when compared to other AODV characteristics which were accepted. The characteristics may be perceived as structurally critical for AODV operation but less responsive to performance optimization modifications. Sequence numbers fundamentally, ensures there is no looping in routing and guarantees route freshness (Siddesh, et al., 2022; Yirga, Taye, & Melaku, 2022). Sequence numbers remain unchanged across the varied AODV implementations. Further, Identification of route request messages, prevents processing of duplicate RREQs (Alameri, Komarkova, Al-Hadhrami, & Lofti, 2022; Guidoum, Achour, & Tayeb, 2022; Wang, Zhang, Zhang, Zhao, & Wei, 2022). Dropping of duplicate RREQs is critical in AODV operation, since it saves on bandwidth, avoids packet collisions and lowers routing overheads.

However, implementation of RREQ identification remains structurally constant across AODV implementations. Furthermore, Hop-by-hop communication is important in AODV operation since the protocol does not store the whole source path in the packet under transmission but only the address of the next hop neighbor node. (Ahmadzadeh & Bokharaeian, 2022; Alameri, Komarkova, Al-Hadhrami, & Lofti, 2022; Santana, et al., 2023; Salroo & Sharma, 2023). Neighbor list, is critical in AODV operations since allows for identification of neighbors and routes associated with them. When a route failure occurs, RERR messages are sent to neighbors and invalid routes marked or removed. (Trivedi, Nayak, Padhan, & Mohan, 2021; Guidoum, Achour, & Tayeb, 2022).

The prominence of route discovery aligns with findings reported in several MANET optimization studies. Njoroge, Ndia and Mwangi (2025) observed that most studies they reviewed were on optimization of route discovery in AODV. Further, Alameri et al. (2022) established that modifications to AODV routing discovery mechanism resulted in effectiveness in terms of network overheads, packet delivery ratio, throughput and end-to-end delay. Moreover, Safari et al. (2023) in their study proposed a modified AODV protocol which was able to suppress routing broadcasts during route discovery, thus providing better performance in terms of end-to-end delay, throughput and packet loss. These studies are in support of the expert consensus attained in this research, underpinning the view that route discovery mechanism remains a primary target for protocol optimization.

VI. CONCLUSION AND RECOMMENDATION

The study presents a structured prioritization approach for guiding future research in AODV optimization. As per the experts' consensus, route discovery, route selection, route maintenance route table management, routing updates, number of routes discovered, hop count, time to live and use of hello messages characteristics present the ultimate potential for performance improvement in MANETs. Future research directions could focus on adaptive RREQ flooding control, probabilistic route discovery, dynamic TTL tuning, hybrid route selection, catching of all discovered routes and adaptive route maintenance. However, the rejection of hop-by-hop communication, identification of route request messages, sequence number and neighbor list AODV characteristics imply that the characteristics may be perceived as structurally critical for AODV operation but less responsive to performance optimization modifications. To quantify the performance gains related with modifications of identified AODV characteristics, future studies should complement the expert-based prioritization provided in this research with experimental and simulation evaluations. Further, the researcher acknowledges that the exposure and the working experience of panel of experts in MANET simulations and in real life deployment could influence the results of prioritization and ranking of the AODV characteristics. Future studies could perform sensitivity analysis by including panel of experts from diverse geographic regions to examine whether the ranking remains consistent across panels.

REFERENCES

Ahmad, M., Hameed, A., Ikram, A. A., & Wahid, I. (2019). State-of-the-Art Clustering Schemes in Mobile Adhoc Networks: Objectives, Challenges and Future Directions. *IEEE Access*, *7*, 17067–17081. https://doi.org/10.1109/access.2019.2893650

Ahmadzadeh, S., & Bokharaeian, B. (2022). A Heuristic-Based Approach for Improvement the Performance of Probabilistic AODV Routing Algorithms in MANETs. *Proceedings of the 2022 8th Iranian Conference on Signal Processing and Intelligent Systems (ICSPIS)*, 1–6. IEEE. https://doi.org/10.1109/icspis56952.2022.10043867

Alameri, I., Komarkova, J., Al-Hadhrami, T., & Lofti, A. (2022). Systematic Review on Modification to the Ad-Hoc On-Demand Distance Vector Routing Discovery Mechanics. *PeerJ Computer Science*, *8*, e1124. https://doi.org/10.7717/peerj-cs.1124

Alani, H., Abdelhaq, M., & Alsaqour, R. (2020). Dynamic Routing Discovery Scheme for High Mobility in Mobile Ad Hoc Networks. *International Journal of Electrical and Computer Engineering*, *10*(4), 3702–3714. https://doi.org/10.11591/ijece.v10i4.pp3702-3714

Anter, S. A., Rahmatullah, B., Khaleefah, S. H., & Tamrin, K. F. (2021). A General Framework for Selecting Appropriate Criteria of Student as Research Assistant Using Fuzzy Delphi Method. *IAES International Journal of Artificial Intelligence (IJ-AI), 10*(4), 839-846. https://doi.org/10.11591/ijai.v10.i4.pp839-846

Arun, M., & Jayanthi, R. (2023). An Adaptive Congestion and Energy Aware Multipath Routing Scheme for Mobile Ad-Hoc Networks Through Stable Link Prediction. *Computer Communications*, *206*, 1–10. https://doi.org/10.1016/j.comcom.2023.03.012

Bairwa, A. K., & Joshi, S. (2020). An Agent Based Routing Search Methodology for Improving QoS in MANET. *Ingeniare. Revista Chilena de Ingeniería*, *28*(4), 708–718. https://doi.org/10.4067/s0718-33052020000400708

Blasco-Blasco, O., Pinto-Delacadena, P. A., Vinueza-Cabezas, A., & Liern, V. (2025). Crafting a Competency-Based Questionnaire Based on Fuzzy Delphi: A Proposal for Enhanced Hiring Process. *Springer*, 1-25. https://doi.org/10.1007/s11135-025-02086-x.

Deepika, S., Nishanth, N., & Mujeeb, A. (2021). An Assessment of Recent Advances in AODV Routing Protocol Path Optimization Algorithms for Mobile Ad Hoc Networks. *2021 Fourth International Conference on Microelectronics, Signals & Systems (ICMSS)*, 1–6. https://doi.org/10.1109/icmss53060.2021.9673632

Eltahlawy, A. M., Aslan, H. K., Abdallah, E. G., Elsayed, M. S., Jurcut, A. D., & Azer, M. A. (2023). A Survey on Parameters Affecting MANET Performance. *Electronics*, *12*(9), 1956. https://doi.org/10.3390/electronics12121956

Guidoum, A., Achour, S., & Tayeb, M. (2022). Enhancing Performance AODV Routing Protocol to Avoid Congestion. *2022 6th European Conference on Electrical Engineering & Computer Science (ELECS)*, 1–5. https://doi.org/10.1109/elecs55825.2022.00030

Hasim, M. A., Jabar, J., Sufian, A., Ibrahim, N. F., & Khalid, F. A. (2023). Employing Fuzzy Delphi Techniques to Validate the Components and Contents of E-Learning Antecedents and Usage Behavior Towards E-Learning Performance. *European Journal of Educational Research, 12*(1), 467-480. https://doi.org/10.12973/eu-jer.12.1.467.

Hung, L., & Quy, V. (2020). A Review: Performance Improvement Routing Protocols for MANETs. *Journal of Communication*, *15*(5), 329–336. https://doi.org/10.12720/jcm.15.5.329-336

Kanellopoulos, D., & Sharma, V. K. (2020). Survey on Power-Aware Optimization Solutions for MANETs. *Electronics*, *9*(1), 1–64. https://doi.org/10.3390/electronics901001

Khaira, K., & Ibrahim, M. M. (2024). Fuzzy Delphi Method for Designing and Developing Acid Base Et-PBL Module to Improve Problem-Solving Skills. *Chimica Didactica Acta*, *12*(2), 45–56. https://doi.org/10.5281/zenodo.1234567

Khatri, P., Shukla, S., Thomas, A., Shiva, A., & Behl, A. (2025). Towards Work Life Fulfilment: Scale Development and Validation. *Journal of Business Research*, *186*, 115006. https://doi.org/10.1016/j.jbusres.2024.115006

Kumari, A. B., & Rohini, K. (2018). A Review on Security Issues and Gaps in the Literature in Mobile Adhoc Networks. *International Journal of Creative Research Thoughts (IJCRT)*, *6*(1), 748–753. https://ijcrt.org/papers/IJCRT1705111.pdf

Naghipour, M. S., Rahim, Z. A., & Iqbal, M. S. (2024). A 5G Competency Model Based On the Fuzzy Delphi Method. *Journal of Infrastructure, Policy and Development, 8*(10), 1-27. https://doi.org/10.24294/jipd.v8i10.6788

Nguyen, V.-H., Nam, V., Linh, D. M., & Quy, V. (2021). An Improved Agent-Based AODV Routing Protocol for MANET. *EAI Endorsed Transactions on Industrial Networks and Intelligent Systems*, *8*(27), e4. https://doi.org/10.4108/eai.23-6-2021.170241

Njoroge, P. M., Ndia, J. G., & Mwangi, P. M. (2025). A Systematic Review of Ad-Hoc On-Demand Distance Vector Routing Protocol for Performance Improvement in Mobile Ad-Hoc Networks. *International Journal of Wireless and Mobile Networks, 17*(2), 1-17. https://doi.org/10.5121/ijwmn.2025.17201

Oteng, D., Zuo, J., & Sharifi, E. (2022). An Expert-Based Evaluation on End-of-Life Solar Photovoltaic Management: An Application of Fuzzy Delphi Technique. *Sustainable Horizons*, *4*, 100036. https://doi.org/10.1016/j.horiz.2022.100036

Peng, S., Wang, Y., Xiao, H., & Lin, B. (2020). Implementation of an Improved AODV Routing Protocol for Maritime Ad-Hoc Networks. *2020 13th International Congress on Image and Signal Processing, BioMedical Engineering and Informatics (CISP-BMEI)*, 7–11. https://doi.org/10.1109/cisp-bmei51763.2020.9263519

Priyambodo, T. K., Wijayanto, D., & Gitakarma, M. S. (2021). Performance Optimization of MANET Networks Through Routing Protocol Analysis. *Computers*, *10*(1), 2. https://doi.org/10.3390/computers10010002

Rahayu, P., & Wulandari, I. A. (2021). Defining E-Portfolio Factor for Competency Certification Using Fuzzy Delphi Method. *Procedia Computer Science, 197*(2022), 566 - 575. https://doi.org/10.1016/j.procs.2021.12.174

Raju, K. N., Sirisha, A., Nanaji, U., Sharma, S. K., & Kumar, C. R. (2021). An Adaptive Hello Interval for AODV Through ANFIS to Improve the Performance of MANETs. *International Journal of Knowledge-based and Intelligent Engineering Systems, 25*(2021), 235-242. https://doi.org/10.3233/kes-210067

Rathod, V. U., Gumaste, S. V., & Bagadi, K. (2024). Optimizing Path Selection in Dynamic Autonomous Mobile Ad Hoc Networks:A Clustering Approach for Variable Nodes. *Journal of Optimization, 2024*, 1-17. https://doi.org/1155/2024/1769128

Rejeb, A., Rejeb, K., Keogh, J. G., & Zailani, S. (2022). Barriers to Blockchain Adoption in the Circular Economy: A Fuzzy Delphi and Best-Worst Approach. *Sustainability*, *14*(6), 3611. https://doi.org/10.3390/su14063611

Safari, F., Kunze, H., Ernst, J., & Gillis, D. (2023). A Novel Cross-Layer Adaptive Fuzzy-Based Ad Hoc On-Demand Distance Vector Routing Protocol for MANETs. *IEEE Access*, *11*, 25678–25689. https://doi.org/10.1109/access.2023.3277817

Said, M. S., Volkov, A. S., Martynov, V. S., & Zhuravlev, I. A. (2020). Application of Clustering Methods in MANET. *2020 IEEE Conference of Russian Young Researchers in Electrical and Electronic Engineering (EIConRus)*, 1711–1714. https://doi.org/10.1109/eiconrus48714.2020.9045399

Saif, A. A., & Kumar, K. (2022). Enhance the Performance of AODV Routing Protocol in Mobile Ad-Hoc Networks. *Journal of Physics: Conference Series*, *2327*(1), 012057. https://doi.org/10.1088/1742-6596/2327/1/012057

Salroo, Y. R., & Sharma, N. (2023). Impact Analysis of Various Parameters on the Performance of AODV Routing Protocol in MANET Using NS-3 Simulator. *2023 14th International Conference on Computing Communication and Networking Technologies (ICCCNT)*, 1–6. https://doi.org/10.1109/icccnt56998.2023.10308379

Samurathi, R., & Jayalakshmi, V. (2022). Study of Clustering Schemes in Mobile Ad Hoc Networks. *2022 6th International Conference on Intelligent Computing and Control Systems (ICICCS)*, 694–699. https://doi.org/10.1109/iciccs53718.2022.9788134

Santana, C., Macedo, M., Alves, E., Guerreiro, M. T., Siqueira, H. V., & Bastos-Filho, C. J. (2023). Bio-Inspired Multi-Objective Algorithms Applied on the Optimization of the AODV's Routing Recovery Mechanism. *IEEE Access*, *11*, 90000–90010. https://doi.org/10.1109/access.2023.3322691

Siddesh, G. K., Mallikarjuna Gowda, C. P., Shashidhara, H. R., Sathish Shet, K., Shashi Raj, K., Arunarashmi, V., … Teressa, D. M. (2022). Optimization in the Ad Hoc on-Demand Distance Vector Routing Protocol. *Wireless Communications and Mobile Computing*, *2022*, 7322291. https://doi.org/10.1155/2022/7322291

Teli, T. A., Yousuf, R., & Khan, D. A. (2022). MANET Routing Protocols, Attacks and Mitigation Techniques: A Review. *International Journal of Mechanical Engineering*, *7*(2), 1468–1478. https://kalaharijournals.com/resources/FebV7_I2_164.pdf

Tilwari, V., Dimyati, K., Hindia, M. H. D., Fattouh, A., & Amiri, I. S. (2019). Mobility, Residual Energy, and Link Quality Aware Multipath Routing in MANETs With Q-Learning Algorithm. *Applied Sciences*, *9*(8), 1582. https://doi.org/10.3390/app9081582

Trivedi, V., Nayak, P., Padhan, D. G., & Mohan, N. (2021). Performance Enhancement of AODV Routing Protocol for MANET Using Genetic Algorithm. *2021 Second International Conference on Electronics and Sustainable Communication Systems (ICESC)*, 975–981. https://doi.org/10.1109/icesc51422.2021.9532936

Wane, K., Chopade, N., & Rahate, G. (2021). A Comprehensive Survey of Routing Techniques in MANETs. *Proceedings of the International Conference on IoT Based Control Networks & Intelligent Systems (ICICNIS 2021)*, 1–9. https://doi.org/10.2139/ssrn.3883344

Wang, Z., Zhang, J., Zhang, Y., Zhao, H., & Wei, J. (2022). Comparison of Mobile AdHoc Network Routing Protocols Based on NS3. *2022 IEEE 22nd International Conference on Communication Technology (ICCT)*, 1–6. https://doi.org/10.1109/icct56141.2022.10072455

Yaccob, N. K., Yunus, M. M., & Hashim, H. (2024). A Quest for Experts' Consensus on the Knowledge Domain for an ESL Global Competence Framework Using Fuzzy Delphi Method Analysis. *International Journal of Learning, Teaching and Educational Research, 23*(11), 1-31. https://doi.org/10.26803/ijlter.23.11.1

Yin, T. T., & Hanif, H. (2024). Fuzzy Delphi Method: A Step-by-Step Guide to Obtain Expert Consensus on MUETBot Functionalities. *International Journal of Academic Research in Business and Social Sciences, 14*(4), 1097-1104. https://doi.org/10.6007/ijarbss/v14-i4/21307

Yirga, H. G., Taye, G. D., & Melaku, H. M. (2022). 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*, 5750767. https://doi.org/10.1155/2022/5750767

Yusof, N., Hashim, N. L., & Hussain, A. (2022). A Review of Fuzzy Delphi Method Application in Human-Computer Interaction Studies. *AIP Conference Proceedings*, *2472*, 040026. https://doi.org/10.1063/5.0094417

Yusoff, A. F., Hashim, A., Muhamad, N., & Hamat, W. N. (2021). Application of Fuzzy Delphi Technique to Identify the Elements for Designing and Developing the E-PBM PI-Poli Module. *Asian Journal of University Education (AJUE), 17*(1), 292-304. https://doi.org/10.24191/ajue.v17i1.12625.

Yusoff, H. M., Heng, P. P., Illias, M. R., Karrupayah, S., Fadhili, M. A., & Hod, R. (2024). A Qualitative Exploration and a Fuzzy Delphi Validation of High-Risk Scaffolding Tasks and Fatigue-Related Safety Behavioural Deviation Among Scaffolders. *Heliyon*, *10*(15), e34599. https://doi.org/10.1016/j.heliyon.2024.e34599