Enhanced-AODV Routing Protocol to Improve Route Stability of MANETs

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Abstract: *Establishing and maintaining link stability in Mobile Ad hoc Networks (MANETs) is one of the key challenging issues. Topology changes in MANET because overhead traffic that leads to consuming extra energy of nodes as well as decreasing the performance of routing protocols. Thus, a comprise approach should be considered during the design of a routing scheme in MANETs to deal with challenges incurred by the mobility of the nodes. In this study, a simple efficient routing scheme called Enhanced_AODV (E-AODV) is proposed, aiming to enhance Ad Hoc On-Demand Distance Vector (AODV) routing protocol performance by constructing the most stable and reliable route from source to the destination node. In this routing scheme, the remaining lifetime of links and hop count are the metrics considered for calculating the Route Stability Factor (RSF) that can be utilized as a cost metric to establish the best route between source and destination node. The simulation results reveal that the proposed E-AODV routing scheme effectively outperforms the conventional AODV routing protocol and Stable and Bandwidth Aware Dynamic Routing Protocol (SBADR) in terms of packet delivery ratio, average network throughput, average end-to-end delay, and normalized routing overhead.*

Keywords: *MANET, routing protocol, shortest path, route stability, network density.*

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1. Introduction

Establishing and maintaining link stability in Mobile Ad hoc Networks (MANET) consists of a set of mobile wireless nodes working together to form a temporary network. This type of network allows nodes to establish communication and exchange data packets among nodes without the need for any fixed infrastructure or centralized control [16]. Mobile nodes can communicate with each other directly or use intermediate nodes while they are not in the transmission range of each other [23]. MANETs are suitable for a wide range of applications, particularly in areas where there is a need to establish temporary network infrastructures like disaster areas, temporary crisis management desks, battlefields, and temporary health care service areas. Figure 1 demonstrates a sample application area for MANETs.

The mobility and limited energy source of the nodes are the main challenging issues in the design of MANETs [2, 8]. Due to the mobility of nodes in wireless MANETs, the network topology changes continually and link failures may occur at any time. Dynamic changes in network topology increase the energy utilization of nodes, resulting in reduced network lifetime, and more significantly the routing overhead increases [18].

Classical MANET routing protocols facilitate communication among nodes without the requirement of network infrastructure. These protocols rely on a single routing metric such as the shortest path (minimum hop count), residual energy, or signal strength of nodes to establish the route between source and destination node. This sole metric is not adequate to construct a more stable and reliable route.

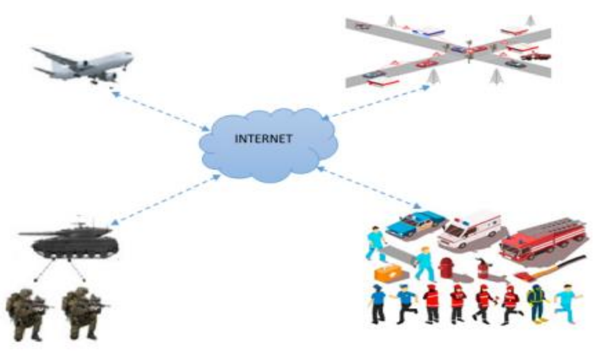

Figure 1. Example of communication applications in MANETs.

In wireless MANETs, the Ad Hoc On-Demand Distance Vector (AODV) routing protocol is one of the most common reactive routing protocols [5]. This protocol uses minimum hop count as a cost metric to choose the route for transmitting data packets and does not consider the node's quality or the route's link stability during the establishment of the route. This results in degraded network performance, reduced network lifetime, and leads to network partitioning issues. To overcome this problem, "Enhanced-AODV" which uses multiple routing metrics and is based on AODV routing protocol has been proposed in this study. Enhanced-AODV considers the remaining lifetime of links and hop counts during the route discovery process. Combining these multiple routing metrics has a crucial role and enhances the route stability and reliability in MANETs.

The major contributions of this research paper are as follows:

1. The E-AODV routing scheme selects a more stable and reliable route for data transmission by considering route stability factors.
2. The proposed scheme takes into account the remaining lifetime of each link (RLT-which uses dynamic movement and positional prediction) and hop count metrics in the candidate node selection process.
3. These metrics are combined in a single metric called Route Stability Factor (RSF).
4. The proposed scheme selects the route with maximum route stability factor as an optimal route among all possible routes to transfer data packets between the source and destination nodes.
5. The performance of the E-AODV is evaluated and compared with two state-of-the-art MANETs routing protocols: AODV [15] and Stable and Bandwidth Aware Dynamic Routing Protocol (SBADR) [19].
6. The proposed scheme validated the MANET routing performance with packet delivery ratio, average network throughput, average end-to-end delay, and normalized routing overhead.
7. The proposed routing scheme is versatile to work for different MANETs. This is because we can easily modify the metrics.

The rest of the paper is organized into different sections as follows. Section 2 demonstrates the related work. The proposed method is presented in section 3. Section 4 demonstrates the simulation results. Finally, the conclusion is provided in section 5.

2. Related Works

Due to the mobility of nodes in MANETs, establishing and maintaining a stable route is a difficult task. A stable route could be defined as a route that has the ability to provide the longest duration of connectivity during the data transfer between source and destination node. Routing protocols in MANETs play a significant role to construct the optimal route for communication. In the last few years, several techniques was proposed for enhancing the route reliability and stability of AODV reactive routing protocol in MANETs. However, most techniques relied on a single routing metric to discover the optimal path between the source and destination node. This section thoroughly presents some of the recently proposed routing schemes related to enhancing the AODV routing protocol performance.

In [12] two models namely node and link quality estimation models are proposed aiming to enhance the stability of the route from source to destination nodes. Node quality estimation model takes into account the energy drain rate, node's energy level, the number of packets forwarded, and the possibility of finding another path from source to destination. The link quality estimation model uses the last three signals arrived to decide the received signal strength value as an indication. The proposed algorithm then uses these two models to decide about dropping or answering the Route Request (RREQ) packets for the route establishment.

Awareness of Link Quality- Ad hoc On-Demand Distance Vector Routing (ALQ-AODV) presented in [13], during the route construction process takes into account the node's residual energy, link quality that is calculated via using the received signal power, transmitter and receiver antenna gains, heights of the transmitter, and receiver, distance, and packet loss. The last parameter taken into account is the degree of the node which is defined as the number of nodes that are one hop away. After the calculation of these three parameters they are compared against a threshold value, and if the threshold values are exceeded the RREQ packages are forwarded or processed. As a result, a stable route could be established.

For optimal routing in [14], a mobility and obstacle aware optimal routing algorithm is presented via calculating an optimal parameter that combines the Realistic mobility pattern with Bazier Curve for obstacle-aware routing and a mobility indication predictor for a mobility aware optimal routing.

Hamad *et al*. [7] proposed two techniques to improve the route stability in the AODV routing protocol. In the first proposed technique, the Link Life Time (LLT) and the Residual Energy (RE) of the nodes are considered for route establishment. In this case, forwarding or discarding an RREQ packet relies on threshold values of LLT and RE of nodes. If the LLT and RE values of neighbor nodes are less than predefined threshold values, the source node cannot broadcast its RREQ packets to them. To overcome this issue, the authors suggested another routing technique based on the average values of the LLT and RE metrics to discover a stable route between the source and destination node. However mobile nodes with very low residual energy may participate in the routing process which results in increased link breakages and decreased network lifetime. To obtain route stability, Kumar and Gupta [10] proposed a routing scheme called route stability and energy-aware-based AODV, Route Stability and Energy Aware-Ad hoc On-Demand Distance Vector Routing (RSEA-AODV). The signal strength, residual energy, and energy depletion of nodes have been used as cost metrics during route selection. All these metrics are compared with a defined threshold value. If the calculated value satisfies the threshold condition then the node processes the RREQ packet otherwise discards the packet. The Palani *et al*. [11] proposed a technique to establish a more stable connection in MANETs by predicting the node mobility and link quality. This scheme used future positions and distance between neighboring nodes to calculate the stable route to the destination node.

For improving data transmission in MANETs Srinivasan *et al*. [20] proposed Load and Stability Aware AODV (LSA-AODV) protocol. Fuzzy logic is applied to the stability metric and traffic density of the route. The ultimate intention is to select a reliable route for data communication and to decrease the number of route breakages, collisions, and contention. It also uses traffic density and stability metrics to control the forwarding of routing packets. Besides, the Colony Optimization-Ad hoc On-Demand Distance Vector Routing (ACO-AODV) routing scheme was proposed in [3] to improve route stability and energy efficiency of the AODV routing protocol in MANETs. This scheme considered multiple metrics of nodes such as residual energy, energy drain rate, speed, and hop count to establish the optimal route between source and destination node. This method enhances the packet delivery ratio and expands the lifetime of the network. Enhanced-Ant_AODV for selecting the optimum route in MANET is proposed by [17]. Residual energy, number of hops, end-to-end route reliability, and congestion of the nodes are used to calculate the optimal route. Sharma *et al*. [19] proposed a SBADR protocol to construct an optimal route based on estimating received signal strength, available link bandwidth, and energy level of nodes. In this study, the bandwidth available is calculated based on the amount of bandwidth available for communication at a particular time on a link. Abbas *et al*. [1] and Er-rouidi *et al*. [6] used a fuzzy logic system to enhance the AODV routing protocol performance. In their study, most trusted nodes used to participate in the route, and as a result, a more stable route between the source and destination node can be chosen.

Xu *et al.* [24], via using outage probability performance showed us that with accurate predictions, interruptions (route errors) can be reduced, and the Quality of Service (QoS) can be improved which in turn could directly be used to improve the stability and the performance of routing protocols.

3. Proposed Work

In MANET, a conventional AODV routing protocol relies on a minimum hop count as a cost metric to find the shortest path between the source and destination node. However, only this metric is not always adequate to find the optimal route. To overcome this issue a new routing approach called Enhanced-AODV (E-AODV) is proposed. Unlike existing proposed approaches to enhance the performance of AODV routing protocol in MANETs, the proposed scheme takes a simple scheme into account to construct a reliable and stable route between source and destination node. E-AODV considers the remaining lifetime of links and hop count as cost metrics to calculate the RSF. RSF has a crucial role in choosing a stable route.

3.1. Estimation of Route Stability Using Reliability Metric

The instability of links has an important effect on network connectivity, routing performance, packet delivery ratio, end-to-end delay, and network throughput. In this section, the metrics that are used in the proposed scheme for constructing the stable route to a destination node are explained.

3.1.1. Remaining Lifetime of Links (RLTl)

Wireless links are directly affected by the remaining lifetime of links. Therefore, to increase the forwarding reliability of a link and reduce the retransmission of packets, a well-known Remaining Lifetime of Link module is considered to predict the stable and reliable link between the current node and the previous node in MANETs. The node's dynamic movement and position prediction are used to calculate the remaining lifetime of links. The two nodes N_1 and N_2 have a transmission range (*r*), the positional coordinate of the wireless mobile nodes *X* and *Y* are represented as (p_1, q_1) and (p_2, q_2). V_1 and V_2 are the speed of the nodes and θ_1, θ_2 ($0 \leq \theta_1, \theta_2 \leq 2\pi$) represents the node's direction. *S* and *D* illustrate the speed of the node from the source to the destination node. The distance between the source and destination node is demonstrated as d_1 and d_2. The remaining lifetime of the link is calculated as:

$$\mathrm{RLTl}_{(x,y)} = -(\mathrm{Sd}_2 + \mathrm{Dd}_1) + \sqrt{(\mathrm{S}^2 + \mathrm{D}^2)\frac{\mathrm{r}^2 - (\mathrm{Sd}_1 - \mathrm{Dd}_2)^2}{(\mathrm{S}^2 + \mathrm{D}^2)}} \quad (1)$$

Where

$$\mathrm{S} = \mathrm{V}_1\cos\theta_1 - \mathrm{V}_2\cos\theta_2 \quad (2)$$

$$D = V_1 sin\theta_1 - V_2 sin\theta_2 \quad (3)$$

$$d_1 = q_1 - q_2 \quad (4)$$

$$d_2 = p_1 - p_2 \quad (5)$$

The value of the remaining lifetime of links is normalized as follows:

$$\mathrm{RLTl}_{nor} = \frac{\mathrm{RLTl} - \mathrm{MaxRLTl}}{\mathrm{MaxRLTl} - \mathrm{MinRLTl}} \quad (6)$$

When the RREQ packet is broadcasted by the source node, the content of the packet is updated to include the data regarding the direction of the neighbor node, speed, and location. In this stage, the RLTl from the source node to the current node is also calculated by the neighbor node. After that, the process of computing the lifetime of the link is finished and the broadcasting of the RREQ packet is halted. Then, the following equation is used to compute the Route Duration Time (RDT) of the shortest route:

$$RDT_{(s,d)} = MIN\{RLTl^{1}_{s,n_1}, RLTl^{2}_{n_1,n_2}, RLTl^{3}_{n_2,n_3}, \dots, RLTl^{i}_{n(i-1),d}\} \quad (7)$$

Where *RDT* represents the minimum *RLTl* value of all possible routes between the source and destination node.

3.1.2. Hop Factor (HF)

Hop count is the total number of hops to transmit a packet from the source to the destination node. In this study, the number of hops is used to calculate the route stability factor at the destination node. The hop factor is calculated as follows:

$$HF_{(s,d)} = \frac{MaxH_{count} - H_{count}}{MaxH_{count}} \quad (8)$$

Where $MaxH_{count}$ is the maximum number of hops allowed by a protocol. H_{count} denotes the hop count between source and destination nodes. The range of *HF* values changes between [0, 1]. A higher value of *HF* indicates a shorter route. When the number of intermediate nodes increases, *HF* value decreases.

3.1.3. Calculation of Route Stability Factor (RSF)

As mentioned before, conventional AODV routing protocol chooses the route for data transmission from the source to the destination node based on minimum hop count without considering a route's link stability factor or node quality during the route establishment. In the proposed routing selection process, two significant metrics namely *RDT* and *HF* are considered. These metrics are combined in a single metric called RSF. RSF essentially chooses the route with a minimum number of hops with a maximum connection lifetime; that means this is the most reliable and stable route for data transmission from the source to the destination node [9, 22]. RSF is mainly a difference of normalized values of the Remaining Lifetime of Links (RLTl) and Hop Factors (HF). RSF of a route can be calculated as follows:

$$RSF_{(s,d)} = \left(\alpha_1 * \frac{RDT_{(s,d)}}{MaxRDT_{(s,d)}}\right) + (\alpha_2 * HF_{(s,d)}) \quad (9)$$

Where α_1, α_2 are the weight factor of each metric with conditions $\alpha_1+\alpha_2=1$. Here, the most important consideration of the two metrics can be updated using weight coefficients. According to the requirements of the application, these weighted coefficients can be flexibly varied to change the significance of the metrics during the route discovery stage. We select equal weights for both metrics in our simulation to give equal priority to route duration time and hop factor. *MaxRDT* denotes the maximum *RLTl* value among all possible routes obtained at the destination node. The *MaxRDT* is expressed as follows:

$$MaxRDT_{(s,d)} = MAX\{RDT^{1}_{s,d}, RDT^{2}_{s,d}, RDT^{3}_{s,d}, \dots, RDT^{snn}_{s,d}\} \quad (10)$$

For a better understanding of the *MaxRDT*, assume that the source (*S*) node has data packets to be sent to the destination (*D*) node. As shown in Figure 2, three different paths are available between node *S* and node *D*. The values on the links represent the *RLTl*. For example, the *RLTl* value between node S and node N_2 is 50. In this case, the destination node selects the maximum *RDT* among routes.

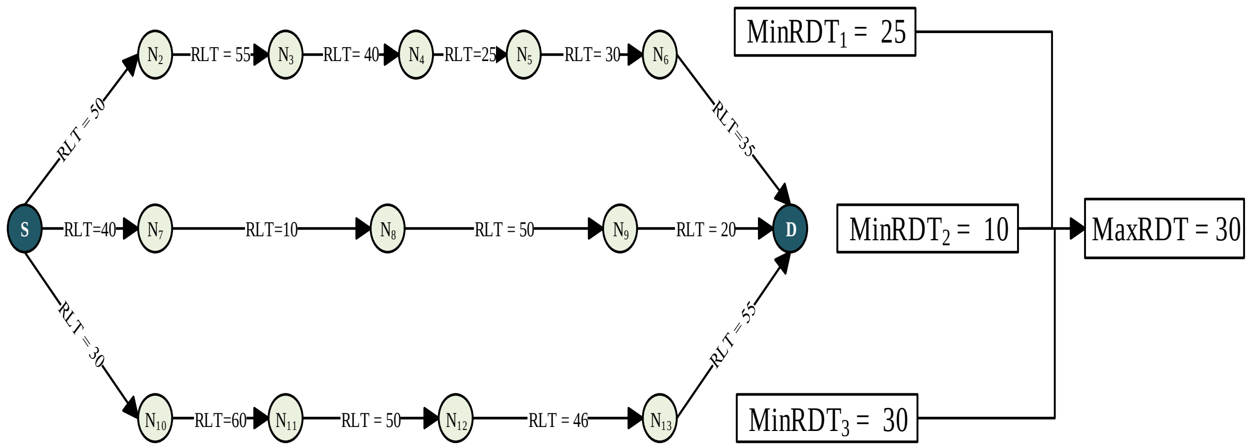

Figure 2. Calculation of route duration time for all possible routes.

3.2. E_AODV Route Discovery Process

The following steps demonstrate the proposed routing scheme to find the optimal route at the intermediate and destination nodes in the E-AODV routing protocol while Figure 3 demonstrates the flowchart of the proposed E_AODV routing protocol.

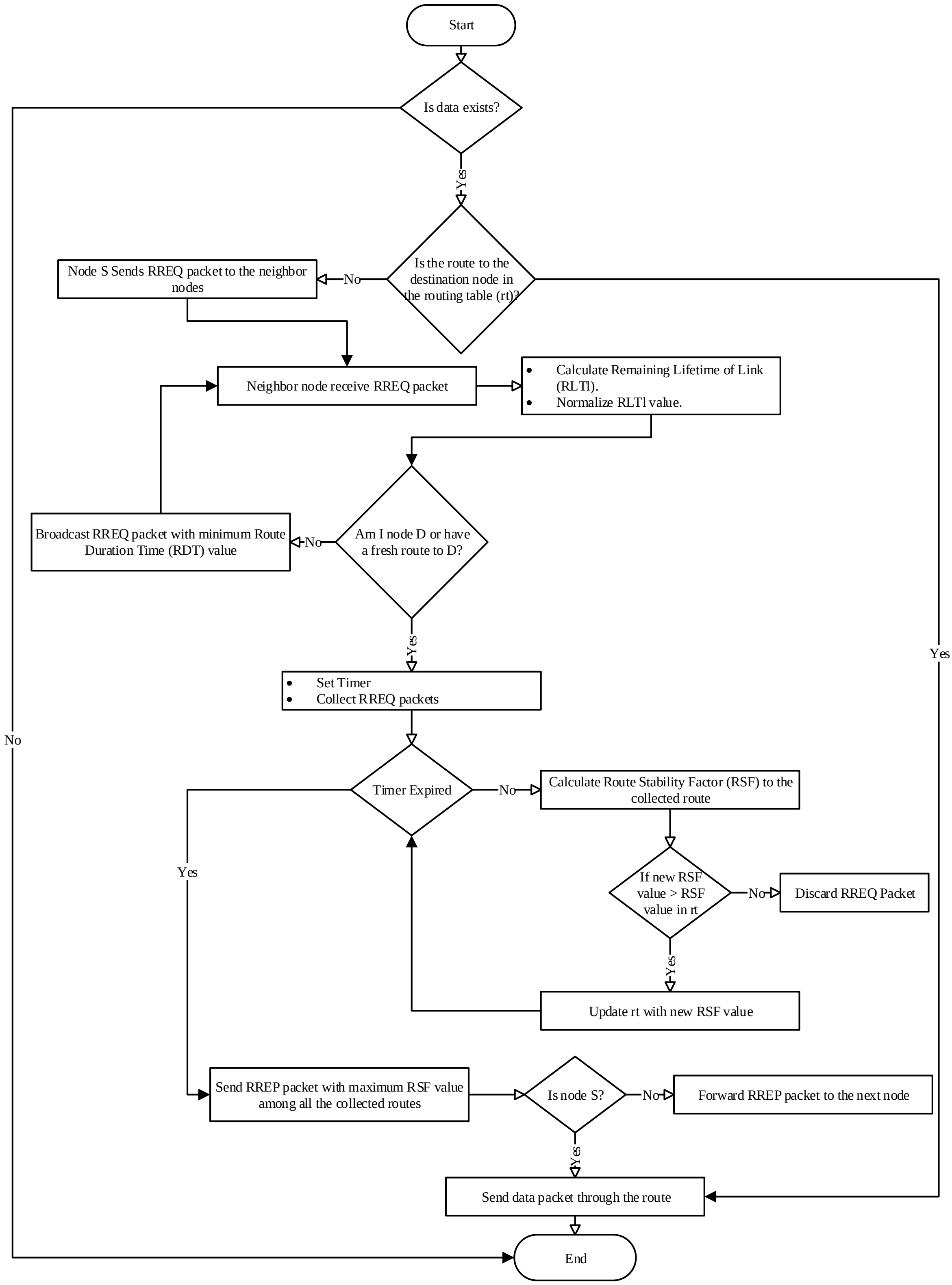

Figure 3. The routing process of the proposed scheme.

3.2.1. Receiving RREQ Packet at the Intermediate Nodes

- *Step* 1: after the network is initialized, when node S needs to transmit data packets to a specific node *D*, it checks whether it has a route to node *D* in its routing table (*rt*). If so, it sends the data through the route.
- *Step* 2: if node S does not have a valid route to node *D* in the local *rt*, it generates a RREQ packet and sends it to all neighbor nodes.
- *Step* 3: the neighbor nodes receive the RREQ packet from node *S*.
- *Step* 4: if the neighbor node receives the RREQ packet for the first time, then it generates a reverse route toward node *S* in its routing table. Later on,

constructing a reverse route is required for transferring the RREP packets from node *D* to node *S*.

- *Step* 5: neighbor nodes calculate the *RLTl* and normalize the *RLTl* value.
- *Step* 6: if the RREQ packet is not the first or the *RDT* value is not better than the existing *RDT* received before in the routing table, then the coming RREQ packet is dropped.

3.2.2. Route Selection at the Destination Node

When node *D* receives the first RREQ packet in the standard AODV routing protocol, it creates the Route Reply (RREP) packet and sends it back to node *S*, and drops other RREQ packets that are received later because of its shortest route construction behavior.

In the proposed routing selection process, when the first RREQ packet is received by node *D*, it does not send back RREP immediately. The following steps are implemented at the node D:

- *Step* 1: node D inspects whether a RREQ packet arrives for the first time or not by observing the node *S* ID and RREQ ID in the *rt*.
- *Step* 2: if it is the first time, it computes Route Stability Factor (RSF) and the value is stored in the *rt*. Then, node *D* has to wait for a small amount of time $\Delta\tau$ to collect additional RREQ packets if any.
- *Step* 3: if it is not the time, then node *D* inspects its waiting time $\Delta\tau$.
- *Step* 4: if the waiting time for collecting the RREQ packet is not expired, then the algorithm computes *RSF* for the newly arrived RREQ packet and makes a comparison with the *RSF* value which has been stored before in the *rt*.

If the RSF value of the newly arrived RREQ packet at node *D* is higher than the RSF value available in the *rt*, then node *D* updates the rt entry with the arrived copy of the RREQ packet. Otherwise, the arrived RREQ packet is ignored.

- *Step* 5: if node *D* receives another RREQ packet before the waiting time $\Delta\tau$ expires, it executes step 4 again.
- *Step* 6: when the waiting time expires, node *D* generates and sends a RREP packet back to node *S*. As a result, node *D* chooses the optimal route based on the highest *RSF* value.
- *Step* 7: when the RREP packet is received by node *S*, it starts sending data packets through that route to node *D*.

3.2.3. Illustration

The execution of the E_AODV routing scheme through an instance is demonstrated in this subsection. To start the route discovery process, node S creates and broadcasts a RREQ packet. The RREQ packet consists of a source ID, source seq No, destination ID, destination seq No, RREQ ID, hop count, and route duration time (*RDT*). The E_AODV route discovery process is demonstrated in figure 2. Suppose that *S* and *D* are the source and destination nodes respectively. Node *S* broadcasts a RREQ packet to neighbor nodes. The *RLTl* value is presented on the links. When a RREQ packet is received by a neighbor node, it first calculates its *RLTl* from node S to itself. Then the node updates the RDT field of the RREQ packet if its *RLTl* is smaller. Suppose that the value of *RLTl* of N_2 and N_3 are 55 and 40 respectively as illustrated in Figure 2. Hence, the minimum *RLTl* is at N_3 and is 40 that is less than the current *RLTl* value on the received RREQ packet from N_2 which is 55, N_3 updates the *RDT* field with its *RLTl* and then rebroadcasts the RREQ packet with the *RLTl* value of N_3. If the new value of *RLTl* at a node is equal to or smaller than the value in the RREQ packet, the *RDT* field is not updated. This procedure continues till the RREQ packet gets to node *D*. When the first RREQ packet reaches node *D*, node *D* initiates a timer and waits for collecting additional RREQ packets. After the expiration of the timer, node *D* creates and sends a RREP message back to node *S* through the best route i.e., through the route that has a higher value of *RSF*. To compare the process of the proposed routing scheme against the conventional AODV about the selection of the optimal route we consider the following cases based upon Figure 2:

- *Case* 1: Conventional AODV routing protocol selects the route with minimum hop count between node *S* and node *D*. According to Figure 2, route from node *S* to node *D* with conventional AODV will be constructed as $S\rightarrow N_7\rightarrow N_8\rightarrow N_9\rightarrow D$ where the path has the minimum hop count when compared to other possible routes.
- *Case* 2: Proposed E_AODV routing protocol selects a route with the maximum value of *RSF*. The *RSF* value of E_AODV for the route $S\rightarrow N_2\rightarrow N_3\rightarrow N_4\rightarrow N_5\rightarrow N_6\rightarrow D$, $S\rightarrow N_7\rightarrow N_8\rightarrow N_9\rightarrow D$ and $S\rightarrow N_{10}\rightarrow N_{11}\rightarrow N_{12}\rightarrow N_{13}\rightarrow D$ is 0.81, 0.59, and 0.91 respectively. Hence, E_AODV chooses the route which has the maximum value of RSF i.e 0.91 for transmitting the data packets. The route will be chosen as $S\rightarrow N_{10}\rightarrow N_{11}\rightarrow N_{12}\rightarrow N_{13}\rightarrow D$.

Case 1 chooses the shortest route without taking into account the *RLTl* between nodes. Consequently, case 1 does not provide a guarantee to construct a stable and reliable route between node *S* and node *D*. Case 2 eliminates the disadvantages of case 1 by taking into account both *RLTl* and hop count as a cost metric. Therefore, the proposed routing scheme always selects the most reliable and stable route for transmitting data packets from the source to the destination node. Basically, E_AODV tries to increase the probability of sending all the data packets from node *S* to *D* without a connection break or a need for a new route construction.

In the route maintenance process, the primary procedure is to discover if the link is broken or active. All the nodes in a route are determined to discover the broken links if there exists any. When the links between two nodes are broken, the nodes will generate and send the Route Error (RERR) message to node *S* and node *D*. If the RERR packet is received by node S, then the route discovery process will be initiated from the beginning.

The pseudocode of the E_AODV routing scheme is presented in Algorithm (1).

Algorithm 1: E-AODV Routing Protocol

Begin Route Discovery Process
Input: rt, Node S, Node D, Intermediate Node (Node T)
Output: Optimal possible route ($R_{optimal}$) from the Node S to the Node D

```
initialize the network by using Eq. (1) and (6)
if (there is a route R_local to Node D then select R_optimal = R_local ) then
    send data through the selected route
else
    broadcast RREQ packet = Node S generates RREQ packet
if (Node T ≠ Node D) then
    Node T:
    calculate RLTl by using Eq. (1) and (6)
    update RDT field in rt by using Eq. (7)
    update RDT filed in RREQ packet = current value of RDT in rt
    broadcast RREQ packet
end if
if (Node T = Node D) then
    Node D:
      calculate the waiting time to collect RREQ packets
      calculate RSF by using Eq.(9)
      update rt based on maximum RSF value
end if
if( Δτ expires) then
    Node D generates and transmits the RREP packet towards Node S with R_optimal (maximum RSF value) between Node S and Node D
end if
    if (Node S receives the RREP packet) then
            Node S:
                update its rt
                send data through the selected R_optimal.
    end if
End Procedure

Begin Route Maintenance Process
  Node S sends a data packet to Node D through R_optimal
  if (the link between two nodes (N_a and N_b) is broken) then
    N_a stores data packet
    N_a sends RREQ packet to N_b and waits for RREP packet
            if (N_a receives the RREP packet) then
                N_a will continue to transmit the rest of the data packet
            end if
  else
    N_a sends RERR packet to Node S
    N_b sends RERR packet to Node D
            if (the REER packet received by Node S) then
            Node S initiates a new route discovery process
            end if
  end if
End Procedure
```

4. Simulation and Environment

The simulation setup details and the comparison of the proposed routing scheme (E_AODV), conventional AODV, and SBADR is presented within this section.

4.1. Simulation Setup

NS2.35 is used to assess and compare the performance of the E_AODV routing protocol against the conventional AODV and SBADR routing protocols under various network densities. Details about the parameters used in the simulations are shown in Table 1.

Table 1. Simulation parameters.

Parameters	Value
Routing protocols	E_AODV, AODV, SBADR
Network area	900m x 900m
Number of nodes	10, 30, 60, 90
MAC protocol	IEEE 802.11
Propagation model	Two ray ground
Type of antenna	Omnidirectional
Transmission range	250m
Mobility model	Random waypoint
Traffic type	CBR (UDP)
Data packet size	512 bytes
Data packet rate	4pkt/s
Maximum node speed	10m/s
Pause time	10s
Simulation time	300s

4.2. Evaluation Metrics

Efficient routing protocols can provide important benefits to MANETs in terms of both reliability and performance. Many quantitative metrics can be utilized to evaluate the performance of routing protocols. In this study, common metrics have been used to evaluate the performance of the proposed routing scheme, AODV, and SBADR routing protocols. These metrics are packet delivery ratio, network throughput, average end-to-end delay, and normalized routing overhead.

1. Packet Delivery Ratio (PDR): PDR is the ratio between the numbers of packets received by a destination node successfully to the number of packets transmitted by a source node. The following equation is used to calculate PDR:

$$\text{PDR} = \frac{\sum \text{Number of packets receive}}{\sum \text{Number of packets send}} \tag{11}$$

2. Average Network Throughput: it can be defined as the average amount of data packets that arrive at a destination node from a source node during a period of the network operation time. It is represented in Kbps and can be calculated as:

$$\text{Network Throughput} = \frac{\text{No. of packets received} * 8}{\text{Network simulation time}} \quad (12)$$

3. Average End-to-End Delay (Avg EED): it is expressed as the ratio of the entire time taken to transfer the data packet between a source and destination node to the number of data packets received at the destination node. In this performance, metric queuing, route discovery, and retransmission delays are taken into account. Avg. EED can be computed as follows:

$$Avg. EED = \frac{Total\ time\ taken\ to\ transfer\ data\ packet}{No. of\ data\ packet\ received} \quad (13)$$

4. Normalized Routing Overhead (NRO): it is defined as the total number of control packets generated per data packet that reaches the destination node. Routing protocols with less NRO can provide better performance. NRO value increases if route breakages occur during data communication.

4.3. Results and Discussion

In this section, the performance of the proposed E_AODV routing scheme with the AODV and SBADR routing protocols is compared. Table 2 shows the simulation results obtained for three routing protocols using the metrics described above.

Table 2. Simulation results.

No. of Nodes	Protocol	Metrics			
		PDR (%)	Avg. Throughput(Kbps)	Avg. EED (s)	NRO
10	AODV	98.78	16.74	0.041	45.51
	SBADR	98.83	16.81	0.029	43.89
	E_AODV	99.27	16.95	0.019	25.18
30	AODV	98.46	16.68	0.051	84.03
	SBADR	98.63	16.72	0.042	72.28
	E_AODV	99.18	16.91	0.022	30.25
60	AODV	97.92	16.66	0.086	154.23
	SBADR	98.141	16.69	0.057	124.89
	E_AODV	98.85	16.88	0.033	85.63
90	AODV	97.74	16.53	0.132	230.3
	SBADR	97.983	16.62	0.11	212.24
	E_AODV	98.61	16.77	0.077	181.97

Figure 4 demonstrates the simulation results obtained for PDR. It can be observed that the proposed protocol has a higher delivery ratio in all considered network scenarios compared to both routing protocols. E_AODV selects the most effective and stable candidates along the route and spans a longer time. Therefore it decreases the RREQ packet retransmissions over the network. Consequently, the E_AODV routing scheme reduces the routing overhead, channel contention, and packet collision. Average throughput is also increased with E_AODV which means more data packets can be delivered during the network simulation time.

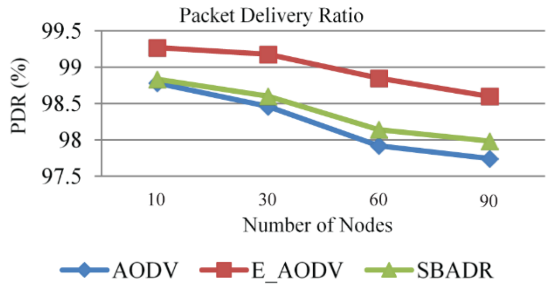

Figure 4. Packet delivery ratio vs. no. of nodes.

Figure 5 shows the average network throughput of the proposed routing scheme in contrast to AODV and SBADR with increasing network density. E_AODV scheme considers the remaining lifetime of links and minimum hop count as a cost metric to select the best candidates during the route discovery process. Thus, it improves the network performance by maximizing the performance of one-hop node along the route, as the performance of one-hop enhancement donates to the end-to-end performance. In contrast, the average network throughput of the SBADR and AODV routing protocol is less than the E_AODV routing scheme. It is due to the fact that wireless link connections on SBADR and AODV are lost rapidly with neighbor nodes as the topology of the network changes and the size of the network increases. The control packets generated and disseminated through the network significantly increase, which creates significant routing overhead. The necessity of pre-calculated routes in SBADR and AODV improves network connectivity at the expense of routing performance [4]. Consequently, as the network density increases the network throughput reduces linearly.

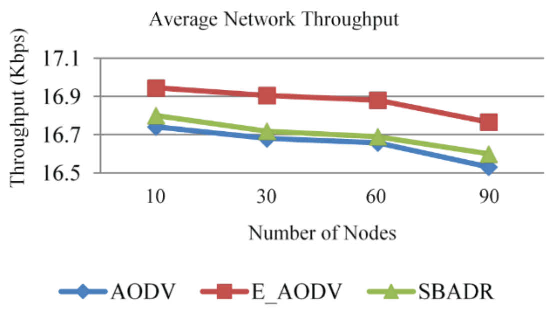

Figure 5. Average network throughput vs. no. of nodes.

The results demonstrated in Figure 6 depict the performance of three routing protocols in terms of average end-to-end delay. It can be observed that as the number of nodes increases, the average end-to-end delay increases for three routing protocols. It is due to the fact that in dense networks, more routing packets are generated and disseminated in the network, and hence the interference among neighbor nodes, channel contention, and message collision increases. Therefore, the destination node requires more time to receive packets. On the other hand, when the network is sparse, the routing packets are not succeeded to arrive at the destination node due to poor connectivity, and thus the end-to-end delay latency increases in the network. For the AODV routing protocol, we can observe that the average end-to-end delay increases more notably as the number of nodes increases compared to both routing protocols. The reason behind this is the AODV routing protocol does not into account the route stability factor when establishing the optimal route between source and destination nodes. Thus, the routes constructed in the AODV routing scenarios are broken more frequently than with E_AODV and SBADR. However, the average end-to-end delay of E_AODV outperforms SBADR and AODV under varying network densities, by considering the route stability factor to find the optimal route for data communication.

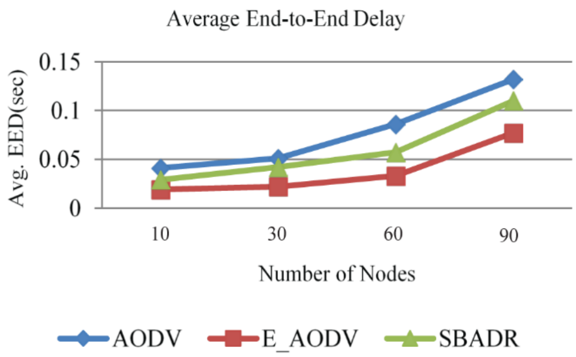

Figure 6. Average end-to-end delay vs. no. of nodes.

Figure 7 illustrates the normalized routing overhead versus the number of nodes. The results showed that routing overhead increases as the number of nodes increases for all routing protocols. This is because in the large network density more route request packets are generated and rebroadcasted over the network. However, the E_AODV routing scheme generates less routing overhead as compared to both AODV and SBADR routing protocols since it considers both the remaining lifetime of the link between two nodes and hop count as a cost metric, unlike the AODV routing protocol. In addition, during establishing a stable route, the E_AODV scheme avoids the nodes which change their positions frequently and quickly. This plays a significant role to reduce route breakage. The results also reveal that for a given network density, the normalized routing overhead generated by SBADR is lower compared to AODV. This is because SBADR considered bandwidth and energy metrics with signal quality during routing decisions which means, route break is less when compared to AODV.

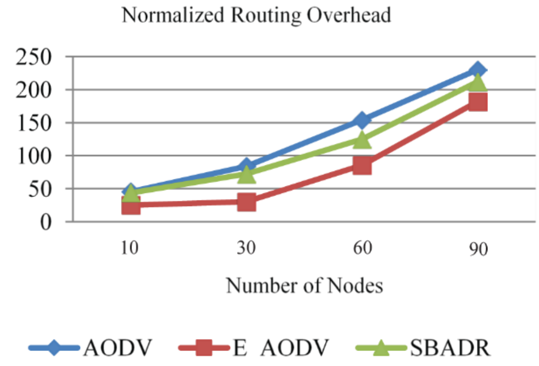

Figure 7. Normalized routing overhead vs. no. of nodes.

As an additional metric, the time complexities of the proposed algorithm, AODV and SBADR are compared. The time complexity of the standard AODV routing protocol is O(2*d*) where *d* is the diameter of the network [21]. The proposed Enhanced_AODV algorithm adds an addition loop into standard AODV routing protocol in terms of computational time complexity, which allows the destination node to collect RREQ packets for a specific period of time (until the timer expires) and decide upon the most reliable route using their RSF values. Since the timer value is constant and does not depend on any input size N, the proposed algorithm is said to increase the computational time over standard AODV with a constant time complexity order of O(1). On the other hand, the SBADR algorithm also allows the destination node to receive multiple RREQ packets and select the optimal route based on estimating received signal strength, available link bandwidth, and energy level of nodes. Similarly, this algorithm is said to have an additional constant time complexity with order O(1), since the waiting time does not depend on the input size N. Therefore, irrespective of the input size N, the additional runtime over AODV will always be the same as the proposed Enhanced_AODV algorithm.

As a result, the experimental results show that, in terms of packet delivery ratio, average network throughput, average end-to-end delay, and average routing overhead, the proposed algorithm performs better than standard AODV and SBADR routing schemes. Although time complexity of the proposed algorithm is increased by O(1) over AODV, the simulations were performed for a different number of nodes (10, 30, 60, and 90) and it has been seen that the proposed algorithm outperforms AODV and SBADR in all the scenarios. On average, the proposed algorithm improved the packet delivery ratio, average network throughput, average end-to-end delay, and average routing overhead by 0.75%, 0.23 kbps, 0.04 sec, and 47.76%, respectively.

5. Conclusions

In wireless networks, link stability problems can be efficiently minimized by considering the remaining lifetime of communication links among nodes. In this paper, a new routing scheme named Enhanced_AODV (E_AODV) has been proposed to improve the performance of conventional AODV routing protocol in MANETs. E_AODV considers the remaining lifetime of each link and hop count metrics and combines them in a single metric called Route Stability Factor. The route with maximum route stability factor among all possible routes is selected as an optimal route to transfer data packets between the source and destination nodes. The proposed routing scheme reduces the link breakages and in turn, minimizes the number of control packets sent in the network. The efficiency of the proposed routing scheme is demonstrated using computer simulations. Experimental results showed that the E_AODV routing scheme significantly provides better results compared to both the AODV and SBADR routing protocols in terms of packet delivery ratio, average network throughput, average end-to-end delay, and normalized routing overhead.

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