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A Cross-Layer Design and Fuzzy Logic based Stability Oriented Routing Protocol

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Abstract: Ad-hoc networks in which nodes are mobile as well as communicate via wireless links fall under the category of mobile ad-hoc networks (MANETs). Evasive mobility and the limited battery life of MANET nodes make routing a difficult problem. Most of the conventional routing protocols recommend the shortest path without considering route stability into account. A Cross-Layer Design and Fuzzy Logic based Stability Oriented (CLDFL-SO) routing protocol is proposed in this research, which offers a solution for stable route formation by eliminating unstable links and low-quality nodes. Cross-layer interaction parameter based link residual lifetime calculation is used to assess the link's stability. The fuzzy logic is being used to evaluate the node quality by providing node metrics like node speed, residual energy and node degree. The simulations illustrate the efficacy of the suggested protocol in comparison to the popular Ad-hoc On-Demand Distance Vector (AODV) protocol.

Index Terms: Ad-Hoc Networks, MANET, Cross-Layer Design, Fuzzy Logic, Stable Route.

1. Introduction

MANET [1] consists of wireless mobile nodes in order to form the infrastructure-less network. Such networks have unique qualities like low-cost infrastructure, mobility and self-organization which allow them to be used in a variety of applications [2] such as military communications, IoT, disaster assistance, remote surveillance, VANET and so on. Because mobile nodes in MANETs can communicate via a single hop or multiple hops, routing is a prerequisite. With the help of routing protocols, an optimal and loop-free route can be established between source and destination. Routing protocols can majorly be categorized in Reactive, Proactive and Hybrid protocols [3]. In reactive routing protocols like Ad-hoc On-Demand Distance Vector (AODV) [4] route search process starts when data transmission is required. In proactive routing, protocols like Destination Sequenced Distance Vector (DSDV) [5] the routing information is maintained before data transmission starts. Hybrid protocols like Zone Routing Protocol (ZRP) [6] merge the most advantageous features of reactive and proactive routing protocols.

The link stability and the node quality are two fundamental features influencing the efficacy of routing. The stability of an individual link is determined by link residual lifetime, while the node quality ischaracterized by node speed, limited battery capacity and node degree etc. The number of nodes within the communication range is referred to as the node degree [7]. A higher node degree implies a higher probability of its inclusion in the route. Such nodes consume more energy due to handling more packets. The main goal of conventional routing protocols is to determine the shortest route without taking account of the links stability or the node quality during route formation. Considering this shortcoming, the authors have proposed a novel CLDFL-SO routing protocol that excludes unstable links and low-quality nodes. The suggested protocol is based on the traditional AODV routing protocol in which whenever a node receives a route request packet, it first calculates the node parameters and then uses them in a fuzzy logic-based decision-making process to evaluate the quality of the node. The low-quality nodes are not allowed to be part of the route. In this way, the proposed protocol finds a stable path by excluding low-quality nodes. Numerous protocols have been explored in the literature that take either link stability or node quality into account during route formation; however, our suggested protocol takes both link stability and node quality into account during route establishment.

To the best of the author's experience, CLDFL-SO routing protocol is the first that combines the stability of the link calculated by the cross-layer design and the node quality evaluated by fuzzy logic. The link stability is calculated using a cross-layer interaction parameter that is received signal strength (*RSSI*). In cross-layer design [8], every layer of the network is defined by some key parameters, which are then passed on to the non-adjacent layer for efficient use of network resources. Here RSSI is the key parameter of the physical layer and it is passed to the network layer for estimating the link residual lifetime which is used to assess the link stability. In the suggested work, the node quality is evaluated by considering node parameters (node speed, residual energy and node degree) as input to the fuzzy logic. In this way, the proposed CLDFL-SO routing protocol finds a stable path by excluding unstable link and low-quality nodes.

Our Contribution

- Evaluation of the link stability status (LSS) by a cross-layer design based link residual lifetime estimation.
- Assessment of the node quality by considering node speed, residual energy and node degree as input to the fuzzy logic based module.
- Proposing the stable data transmission route selection based CLDFL-SO routing protocol.
- The proposed routing protocol is simulated and its performance is benchmarked against the AODV routing protocol, taking into account normalised routing overhead, end-to-end delay, packet delivery ratio as well as throughput.

Following is the breakdown of the paper's structure: The literature on this topic is presented in Section 2. A novel CLDFL-SO routing protocol for extending network lifetime is described in Section 3. The performance of the CLDFL-SO routing protocol is examined in Section 4. The final section contains some conclusions.

2. Literature Survey

In [9], the authors have suggested a routing protocol for choosing a good quality path by acknowledging various QoS metrics like end-to-end delay, the number of intermediate hops and bandwidth. In [10], the authors discussed a routing algorithm that is based on fuzzy logic for searching an optimal path for communication between the source (S) and destination (D). Every node in the network selects the next suitable successor node based on the channel parameters: signal strength and noise ratio, but the protocol does not observe the node parameters while selecting the next successor node. In [11], the authors discussed an effective fuzzy-based energy efficient load distribution strategy that takes into account energy usage while taking congestion into account as a parameter. In contrast to several existing energy-aware routing algorithms, the suggested strategy improves overall energy usage, network lifetime significantly. In [12], the authors presented a fuzzy logic based approach for computing the stability of the link by acknowledging the energy and movement factor of the node. The link stability is calculated before transmitting the packets.

In [13], the authors outlined a fuzzy logic based method which consists of five input parameters node density, centrality, number of hops, energy and distance to the base station for electing root efficiently. They also incorporate load balance, scalability mechanisms, fault tolerance and timeliness mechanisms. In [14], the authors outlined an approach based on fuzzy logic for improving the performance of AODV by choosing the trustworthy nodes for constructing the path between the source (Src) and destination (Dest). Residual energy, number of hop counts and node mobility are supplied as input parameters to a fuzzy inference system for calculating trust value. In [15], the authors outlined a routing protocol for enhancing the system performance; the route is selected on basis of battery power and mobile node speed. In [16], the authors have introduces a routing protocol for MANET that provides a high-quality route for data transmission. There are two main phases in the protocol. The first stage is to select candidate nodes based on fuzzy logic. In the second phase, multiple routes are established through the selected candidate nodes for the building of a routing backbone.

In [17], the authors have proposed a routing protocol based on fuzzy logic. Appropriate paths are chosen and data messages are successfully transmitted using fuzzy inference rules. In [18], the authors proposed a novel protocol to choose a multicast route on the basis of minimum fuzzy cost value. The performance is shown in terms of packet delivery ratio, control overhead, end-to-end delay. In [19], the authors outlined a novel routing protocol for MANETs which is trying to enhance the AODV performance by searching for a trusted and stable route. In [20], the authors outlined a fuzzy-based protocol for improving the performance of traditional AODV. The energy parameters are taken as input parameters for selecting the next hop. The performance is also compared with DSDV, AODV etc.

In [21], the authors have introduced an innovative routing strategy for developing a stable and energy-saving route while discovering the route; a fuzzy decision tool is used. In [22], the authors proposed two routing algorithms. The first routing algorithm tries to improve the QoS of AODV with the help of the mobile software agent (MSA) paradigm by considering some parameters like end-to-end delay, received signal strength and queue length. And the second one is the fuzzy based technique in order to find the optimal path.

In [23], the authors suggested a routing protocol for selecting an optimal route. An optimized algorithm for local route repair is also advised in the case of link failure. These algorithms try to improve the network lifetime. In [24], the authors used Fuzzy Mobility (FM) for resolving optimal route selection and routing issues in the wireless network. The performance is analyzed for traditional ad hoc routing protocols. In [25], the authors outlined an algorithm for a robust network with a stable route based on AODV (SP-AODV), which takes cross-layer communication into account across the physical, MAC and network layers. In [26], the authors suggested a novel routing strategy for Mobile Adhoc

Networks to determine the most dependable and optimal routing paths between source and destination nodes in a MANET. To tackle the above-mentioned demanding goal, the research focuses on a new revolutionary approach in Genetic Algorithm termed Parametric Fitness Based Genetic Algorithm.

3. Proposed Work

The proposed work is a modified version of the traditional AODV protocol for improvising the route discovery procedure and increasing the network performance. The objective of the proposed work is to discover a stable route rather than a shorter route as overhead imposed by the link failure is much higher than the longer route. AODV suffers from frequent link failure because it does not consider the factors which may affect the route while route formation.

3.1. Cross-Layer Desigh based LSS Evaluation

In this section, link residual lifetime has been considered as a measure of link stability. More link residual lifetime leads to better link stability. Estimation of link residual lifetime is based on cross-layer design. Cross-layer design [8] is a concept in which non-adjacent layers share information to improve network performance. Here, *RSSI* is the physical layer's key parameter [27], which is transferred to the network layer for predicting the link residual lifetime.

In the following steps, the suggested link stability evaluation is compiled:

1. Assume that MANET has two adjacent nodes *i* and *j*.
2. Node *i* broadcasts the hello packets with previously defined signal strength.
3. Node *j* receives hello packets and keeps the record of *RSSI* as well as packet arrival time.
4. Node *j* calculates $RSSI_{i,j\,med}$ which is the median of *RSSI* of the last five consecutively received hello packets.
5. If $RSSI_{i,j_{med}} \geq ant_{threshold}$ then *RSSI* pattern analysis is done for five latest hello packets and LSS is assigned. Where $ant_{threshold}$ is predefined receiver antenna sensitivity threshold given by antenna manufacturer [28].

    - Monotonically increasing *RSSI* pattern implies *HIGH* LSS.
    - Random pattern of *RSSI* implies *MEDIUM* LSS.
    - Monotonically decreasing *RSSI* pattern also implies *MEDIUM* LSS.

6. If $RSSI_{i,j_{med}} < ant_{threshold}$ then again *RSSI* pattern analysis is done for five consecutive packets and LSS is assigned as following.

    - Monotonically increasing *RSSI* pattern implies *MEDIUM* LSS.
    - Random or monotonically decreasing pattern invokes Link Residual time estimation module for stability assignment.

7. *Link Residual time estimation:*This is a least-square quadratic regression-based link failure time estimation method [29]. In this approach, the distance between nodes is considered as a variable depending on the time of arrival of the data packet. This distance is calculated using Friis transmission formula [30]. When a monotonous increase in distance pattern is found, an error-optimized quadratic polynomial equation is fitted considering distance as a packet arrival time-dependent variable. A linear system of equations is formulated for least square regression-based quadratic polynomial fitting as given in Equation 1.

$$\begin{bmatrix} n & \sum_{p=1}^{n} T_{i,j_p} & \sum_{p=1}^{n} {T_{i,j_p}}^2 \\ \sum_{p=1}^{n} T_{i,j_p} & \sum_{p=1}^{n} {T_{i,j_p}}^2 & \sum_{p=1}^{n} {T_{i,j_p}}^3 \\ \sum_{p=1}^{n} {T_{i,j_p}}^2 & \sum_{p=1}^{n} {T_{i,j_p}}^3 & \sum_{p=1}^{n} {T_{i,j_p}}^4 \end{bmatrix} \times \begin{bmatrix} g_{i,j} \\ f_{i,j} \\ e_{i,j} \end{bmatrix} = \begin{bmatrix} \sum_{p=1}^{n} dis_{i,j_p} \\ \sum_{p=1}^{n} dis_{i,j_p} T_{i,j_p} \\ \sum_{p=1}^{n} dis_{i,j_p} {T_{i,j_p}}^2 \end{bmatrix} \quad (1)$$

Here dis_{i,j_p} denotes the distance between nodes *i* and *j* at a particular packet arrival time t_{i,j_p} for any p_{th} packet. $e_{i,j}$, $f_{i,j}$ and $g_{i,j}$ are coefficients of quadratic polynomial. The dis_{thresh} between transmitter and receiver can be calculated from $ant_{threshold}$ using Friis transmission formula. This dis_{thresh} will lie on quadratic polynomial at link failure time. Mathematically, it can be expressed as following.

$$dis_{\mathrm{thresh}} = e_{i,j} T^2 + f_{i,j} T + g_{i,j} \quad (2)$$

Sridharacharya formulae [31] can be used to calculate the value of link failure time$\sigma_{i,j_{failure}}$.

$$\sigma_{i,j_{failure}} = \frac{-f_{i,j} \pm \sqrt{{f_{i,j}}^2 - 4e_{i,j}g_{i,j}}}{2e_{i,j}} \quad (3)$$

Difference between $\sigma_{i,j_{failure}}$ and current time is known as residual link lifetime $\sigma_{i,j_{residual}}$.

8. If $\sigma_{i,j_{residual}}$<*Th* implies *LOW* LSS, where *Th* is a predefined threshold time defined by authors. Contrary to this $\sigma_{i,j_{residual}}$>*Th* implies *MEDIUM* LSS.
9. Update this LSSas an additional field of node *j*'s neighbour table for node *i* and new neighbour table format shown in Fig. 5 and discussed in Section 3.3.

3.2 Fuzzy Logic based Node Quality Assessment

Based on previous experience, node parameters that cause link failure are node speed, node degree and residual energy. To evaluate the node quality, these three factors have been considered. Node quality evaluation is done by utilizing a fuzzy logic inference system [32]. Due to the characteristics of MANET, fuzzy logic based decision making cannot be done in a centralized manner. Every node within the network has a fuzzy logic inference system and the node parameters are available at each node, so the calculation of these input parameters and node quality evaluation is done in a distributed manner.

A. Calculation of Fuzzy Parameters

The proposed work evaluates the node quality by assigning input parameters (node speed, residual energy and node degree) to the fuzzy logic inference system.

Node Speed: The mobility of nodes in a MANET is represented by the node's speed [14].

*Residual Energy:*After receiving or transmitting the routing packets, the left energy of the node is known as residual energy [23]. It is expressed by the following Equation 4.

$$Residual\ Energy = \ Initial\ Energy - Energy\ Consumed \quad (4)$$

Where *Energy Consumed* = $Pkt(S) \times T_x + \ Pkt(R) \times R_x$ (5)

T_x = Transmission Energy; R_x = Reception Energy
Pkt(S): No. of Packet Sent; Pkt(R): No. of Packet received

*Node Degree:*In MANET, the node degree [7] indicates the total number of nodes adjacent to one another within the communication range. If the node degree is high then the chances of packets to be routed through it is also high, consequently, more energy will be drained out from the node.

B. Fuzzification and Defuzzification

Fuzzy Systems [32] have three key components fuzzification, a fuzzy inference engine with IF-THEN rules and defuzzification. Fig. 1 depicts the basic fuzzy system used in the proposed work with node speed, residual energy and node degree as input parameters. Fuzzy set membership functions are used to represent input variables during the fuzzification process. The fuzzy output is calculated using IF-THEN rules in the fuzzy inference engine. The fuzzy output is then turned into decisive values using the defuzzification process.

MATLAB [33] is used as a tool for fuzzy calculations. As represented in Fig. 2, Fig. 3, Fig. 4 and Fig. 5 triangular membership functions described by Equation 6 are used for all three fuzzy inputs (node speed, residual energy and node degree) and the fuzzy output (node quality). There are three types of linguistic values in these membership functions: *LOW, MEDIUM* and *HIGH*. Table 1 shows their respective ranges.

$$\mu_B(x) = \begin{cases} 0 & for\ x \leq \ \alpha_1 \\ \frac{x-\alpha_1}{\beta_1-\alpha_1} & for\ \alpha_1 < x \leq \ \beta_1 \\ \frac{\gamma_1-x}{\gamma_1-\beta_1} & for\ \beta_1 < x \leq \ \gamma_1 \\ 0 & for\ x > \gamma_1 \end{cases} \quad (6)$$

$\mu_B(x)$Denotes *B*'s membership function and (α_1,β_1,γ_1) are the value assigned to the membership function.

Fig. 6 shows the fuzzy rule base which is used for mapping the input-output membership functions. The fuzzy inference system is based on the IF-THEN rules as shown in Table 2. These rules contain some special fuzzy logic operators like 'AND' or 'OR', which are used to connect multiple linguistic variables.

Table 1. Ranges for Linguistic Values

Input/ Output	**Parameters**	**Ranges**		
		LOW	***MEDIUM***	***HIGH***
Input	Node Speed	(0, 4, 8)	(4, 8, 12)	(8, 12, 20)
	Residual Energy	(0, 10, 20)	(10, 20, 40)	(20, 40, 60)
	Node Degree	(0, 4, 6)	(4, 6, 10)	(6, 10, 15)
Output	Node Quality	(0,.333,.667)	(.333,.667,.877)	(.667,.887,1)

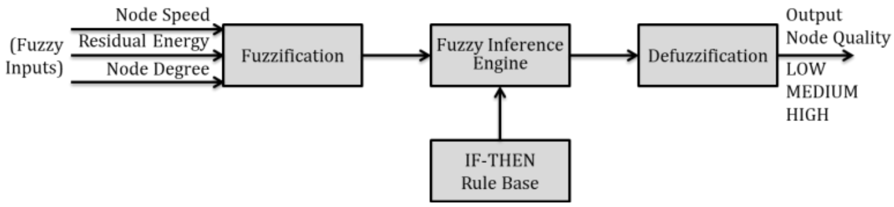

Fig.1. Fuzzy Logic System

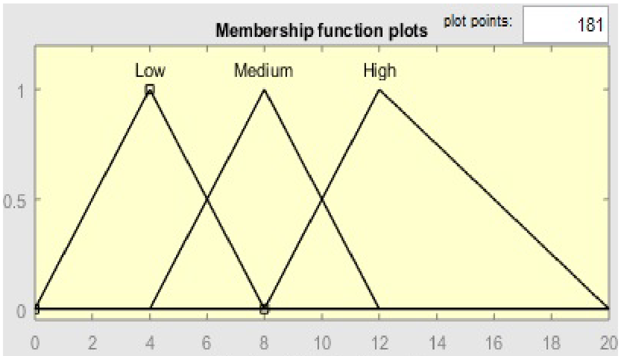

Fig.2. Fuzzy Membership Function for Node Speed(m/s)

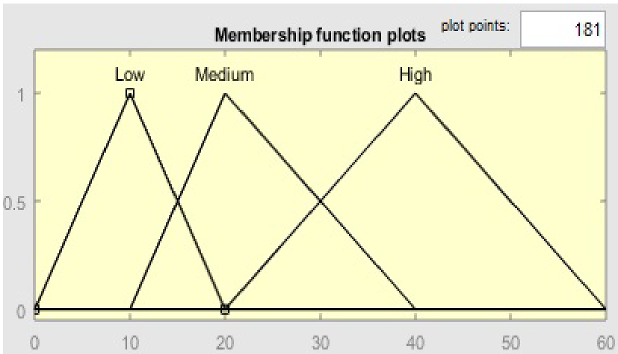

Fig.3. Fuzzy Membership Function for Residual Energy(J)

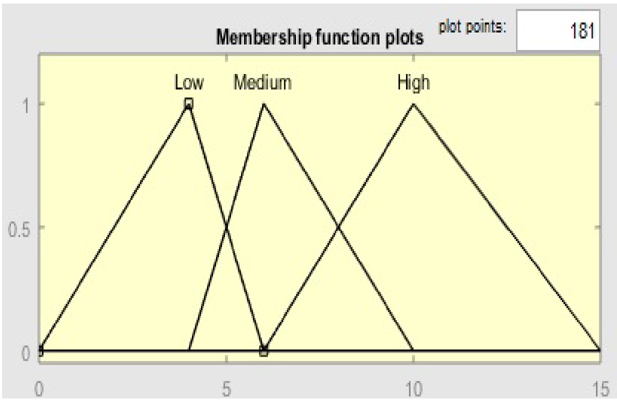

Fig.4. Fuzzy Membership Function for Node Degree

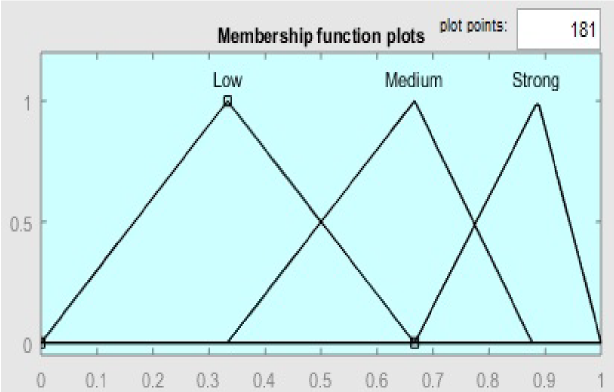

Fig.5. Fuzzy Membership Function for Node Quality

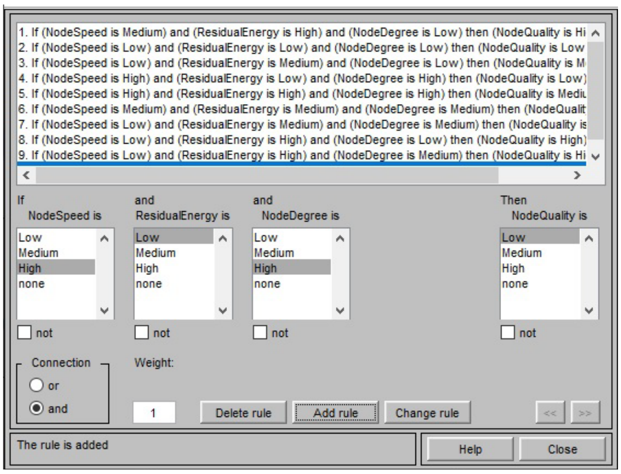

Fig.6. Fuzzy Rule Base

Table 2. Fuzzy Rules

Node Speed	Remaining Energy	Node Degree	Node Quality
MEDIUM	*HIGH*	*LOW*	*HIGH*
LOW	*LOW*	*LOW*	*LOW*
LOW	*MEDIUM*	*LOW*	*MEDIUM*
HIGH	*LOW*	*HIGH*	*LOW*
HIGH	*HIGH*	*HIGH*	*MEDIUM*
MEDIUM	*MEDIUM*	*MEDIUM*	*MEDIUM*
LOW	*MEDIUM*	*MEDIUM*	*MEDIUM*
LOW	*HIGH*	*LOW*	*HIGH*
LOW	*HIGH*	*MEDIUM*	*HIGH*
HIGH	*LOW*	*HIGH*	*LOW*

Defuzzification is a process that generates crisp results from fuzzy results. It is the converse of the fuzzification process. The centroid defuzzification method [34] is applied in this suggested fuzzy model which is described by Equation 7. The fuzzy rule viewer is represented in Fig. 7.

$$COG = \frac{\int \mu(x)xdx}{\int \mu(x)dx} \qquad (7)$$

Where, $\mu(x)$denotes the weight associated with the output membership function defined in Equation 6, each output membership function's centroid is represented by *x* and *COG* represents the defuzzifier output's crisp value.

Example rule: If (Node Speed is *LOW*) AND (Residual Energy is *LOW*) AND (Node Degree is *LOW*) then Node Quality is *LOW*.

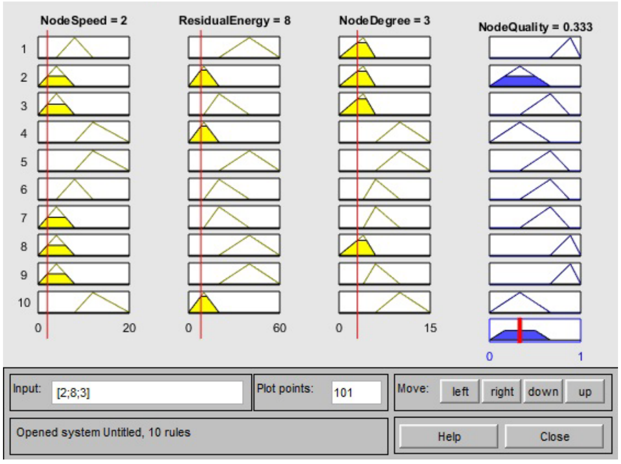

Fig.7. Node Quality Analysis

3.3. *CLDFL-SO Routing Protocol*

This proposed CLDFL-SO routing protocol provides a combined solution for stable route formation by selecting a stable link using cross-layer design as well as avoiding low-quality node using fuzzy logic. When a source node wants to transmit data to the destination node and there is no valid route available, then there is a need for a routing protocol to find the route. This proposed routing protocol includes two phases: Route Discovery Phase and Route Maintenance Phase. Except for the notation of LSS in the Neighbour Table, the Route Request (RREQ), Route Reply (RREP), Route Error (RERR), and Hello control messages, as well as the Routing Table format, are the same as in AODV. LSS is an additional field that is appended in the existing neighbour table of AODV as shown in Fig. 8. This additional entry is filled with *LOW / MEDIUM* or *HIGH* evaluated in Section 3.1.

Neighbour ID	Expiry Time (Seconds)	Link Stability Status (LSS)

Fig.8. Neighbour Table

A. *Route Discovery*

When a source node starts communication, it broadcasts the RREQ packet. After receiving the RREQ packet at an intermediate node, fuzzy input parameters are calculated and then the node quality is evaluated using fuzzy rules. Furthermore, the status of the link stability is queried from the LSS field of the neighbour table for that specific neighbour id from which the RREQ packet is received. If the node quality is *LOW* or the status of the link stability available in LSS field is *LOW* then just drop the RREQ packet in order to avoid the participation of unstable link and low-quality node during the route discovery phase. In this manner, the RREQ forwarding process is repeated until the destination node receives it. In response, the destination node generates an RREP packet and unicasts it back to the node from where the first RREQ packet was received. This process is iterated till the RREP packet is collected by the source node. In this way by excluding the unstable link and low-quality node to be the part of the route, a more stable route is discovered. The steps of the route discovery algorithm can be summarized as follows.

Algorithm 1: Route Discovery Algorithm

```
Input:      Source(S), Destination(D), Intermediate Node(I)
Initialization: S floods RREQ packet
If (I!=D) then
            Link Stability Status= Fetching link stability status from LSS field of neighbour table evaluated by cross-layer design;
            Node Quality =Node Quality Evaluation using fuzzy logic ;
            If Node Quality == LOW Or Link Stability Status == LOW then
                        Drop RREQ packet;
            Else
                        Rebroadcast RREQ packet;
            End
Else
            Stop broadcasting RREQ packet and RREP is generated towards the source
End
Output:     Stable Route
```

Fig. 9 represents the simple topology of MANET, where S and D are the source and destination respectively. Fig. 9(a) shows the route discovery process of traditional AODV routing protocol in which S broadcasts the RREQ packet, all receiving nodes re-broadcast the RREQ packet until it is received by node D. Fig. 9(b) represents the route discovery process of the proposed CLDFL-SO routing protocol in which S broadcasts RREQ packet. When a node receives an RREQ packet, it first checks the LSS field in its neighbour table for the particular neighbour id from which the RREQ was received, and it also evaluates the node quality. If the node quality is *LOW* or LSS is *LOW*, then the RREQ packet is dropped to avoid it being a part of the route. For all other possible combinations of the node quality and LSS, route selection will continue as it is.

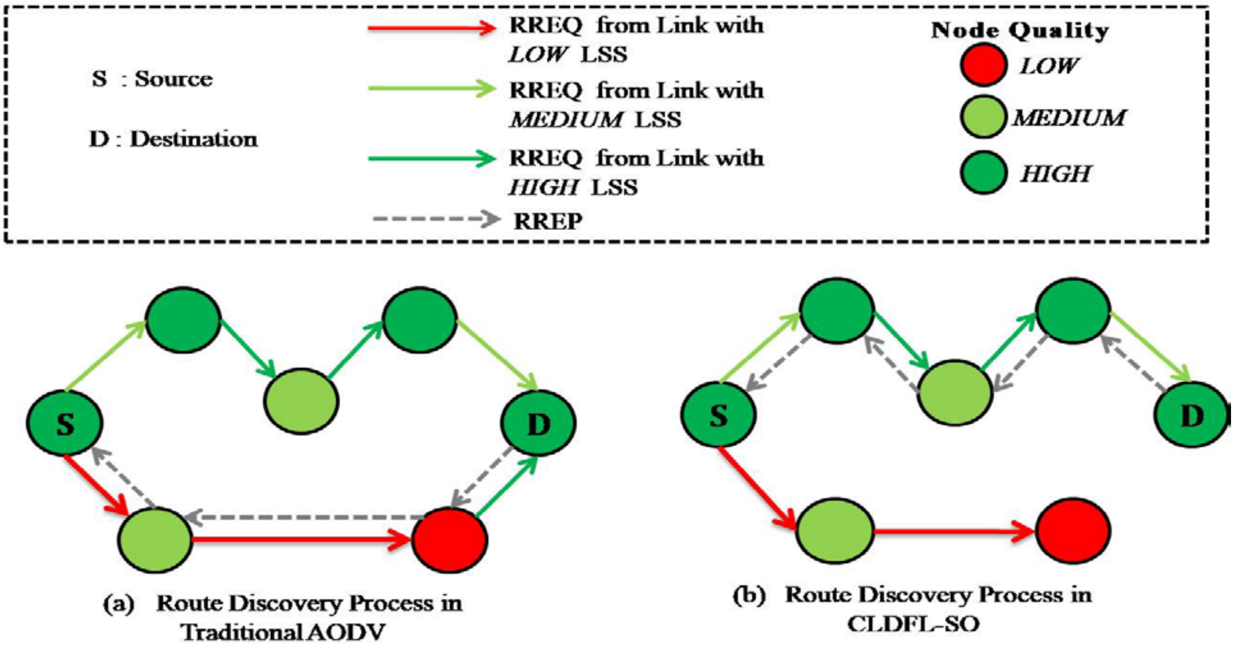

Fig.9. Route Discovery Phase (a) In Traditional AODV (b) In Proposed CLDFL-SO

B. Route Maintenance

Similar to AODV, whenever a link failure occurs in an active route and it is near the destination, then the upstream node tries to repair the link locally. During the local route repair process, firstly data packets are buffered then a new route discovery process is initiated to search the path between the repairing node and destination. Only *HIGH* or *MEDIUM* quality nodes and stable links participate in this new route discovery phase.

4. Result and Discussion

Simulating real-world problems is the most consistent and cost-effective method of examining their performance. NS 2.35 [35] was the primary tool used to create a MANET environment and implementing the routing protocol to evaluate its performance.

41. Assumptions

The following assumptions are made in order to create a robust simulation environment of MANET.

- Nodes are travelling within a two-dimensional fixed rectangular area.
- Nodes communicate with one another via bidirectional links.
- Each node has a fixed and similar communication range.
- Throughout the simulation, the number of nodes remains unchanged.

4.2. Environment Setting

Some parameters must be defined in advance during the simulation process, whereas others are case-specific. For simulation, *2000m×2000m* network area is considered with *50* nodes scattered randomly over the simulation area moving with the maximum velocity of *20 m/s*. AODV protocol has been considered for Performance benchmarking. To mimic the realistic MANET environment simulation parameters are enlisted in Table 3.

Different parameters adopted for examining the performance are listed below.

- *Control Overhead:* The sum of all routing packets (RREQ, RREP, Hello and RERR) transmitted throughout the network.
- *Normalized Routing Overhead:* The ratio of routing packets to data packets received at the destination.
- *End-to-End Delay:* The average time used for transmitting all data packets.
- *Packet Delivery Ratio***:** The ratio of data packets received by destination to data packets sent by the source.
- *Throughput:* The number of data packets received at destination per unit time.

Table 3. Simulation Parameters

Parameters	**Values**
Area	2000 m × 2000 m
Simulation Time	1000 s
Velocity	Min(0 m/s), Max(20 m/s)
Number of nodes	50
Pause Time	0, 20, 40, 60, 80, 100 s
MAC protocol	IEEE 802.11
Propagation type	Two Ray Ground
Initial Energy	60 J
Application Agent	CBR
Packet size	512 bytes
Mobility Model	Random Waypoint Model
Antenna type	Omni Directional Antenna
Communication Range	250m

With varying network topology, the routing simulations have been performed and taken an average of the performance parameters for observing the efficiency of the proposed CLDFL-SO routing protocol. To visualize the performance of the proposed CLDFL-SO routing protocol, Gnuplot utility [36] is used.

4.3. Result Analysis

In Table 3, it is assumed that source nodes transmit a total of 6000 packets and Fig. 10 shows the total number of received packets at target node. On this basis, numerous performance results are generated and the proposed routing protocol's efficacy is demonstrated by comparing to AODV as the benchmark.

Fig. 10 shows the total number of packets arrived at the destination node for both CLDFL-SO and AODV routing protocol with varying pause time. It is observed that compared to traditional AODV, the proposed CLDFL-SO has received more packets at the destination.This is because avoiding unstable links and low-quality nodes reduces link failure. Furthermore, as shown in the graph, the number of received packets increases as the pause time increases. This is because a higher pause time reduces node mobility, which lowers the risk of a link failure.

Fig. 11 represents the end-to-end delay comparison of the proposed routing protocol and AODV. It can be concluded that the proposed CLDFL-SO routing protocol has less end-to-end delay compared to AODV. This is because unstable links and low-quality nodes are avoided during route discovery, which reduces link failure. Therefore, the delay associated with route recovery is minimized. Additionally, as shown in the figure, the end-to-end delay decreases with increasing pause time. This is due to increased pause time reduces node mobility, which reduces link failure.

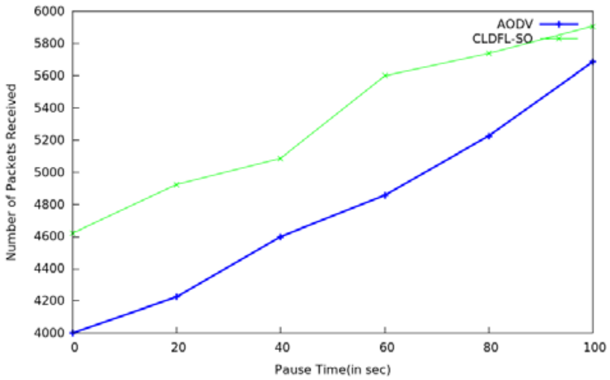

Fig.10. Pause Time vs Number of Packet Recevied

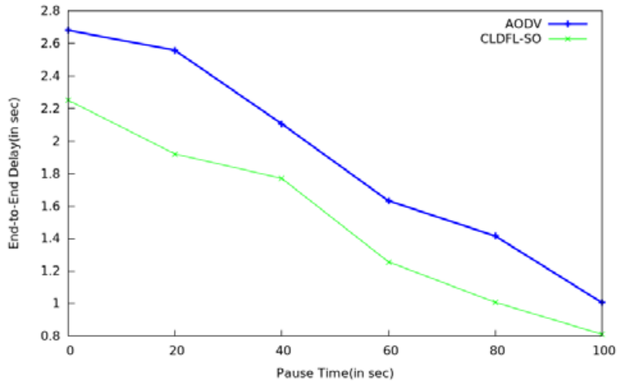

Fig.11. Pause Time vs Delay

Fig. 12 and Fig. 13 show the comparison of control overhead and normalized routing overhead for CLDFL-SO and AODV routing protocol with varying pause time respectively. It is noticeable that CLDFL-SO routing protocol has lower control and normalized routing overhead than AODV, even when pause time varies and contextual features of MANET are taken into account. This is due to a reduction in flooding of routing packets with depreciation in the number of link failure by avoiding unstable links and low-quality nodes during route discovery. It is also observed that increasing pause time, control overhead and normalized routing overhead decreases. This is because increasing the pause time reduces node mobility, which results in a reduction in link failure.

Fig. 14 and Fig. 15 compare packet delivery ratio and throughput as pause time is varied for the proposed CLDFL-SO and traditional AODV, respectively. It is noticeable that the proposed CLDFL-SO has a higher packet delivery ratio and throughput than traditional AODV. This is because link failure is reduced by avoiding unstable links and low-quality nodes. Furthermore, as shown in the figures, the packet delivery ratio and throughput increase as the pause time increases. This is due to the increased pause time reducing node mobility and, as a result, link failure.

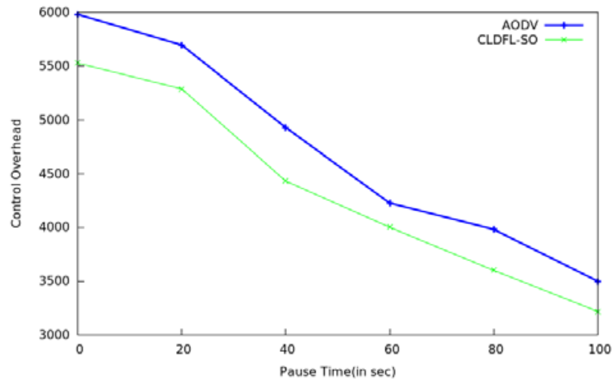

Fig.12. Pause Time vs Control Overhead

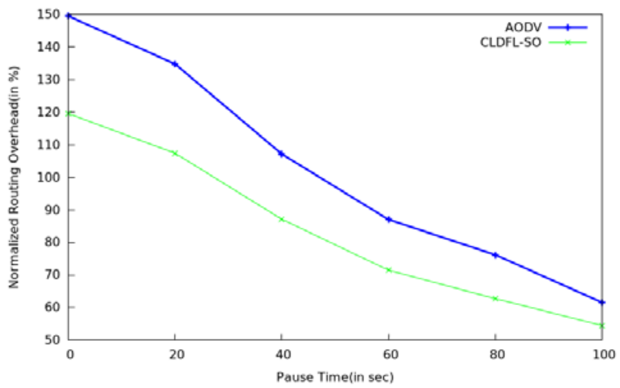

Fig.13. Pause Time vs Normalized Routing Overhead

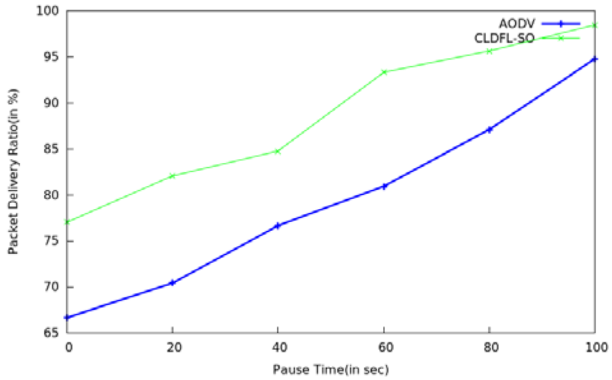

Fig.14. Pause Time vs Packet Delivery Ratio

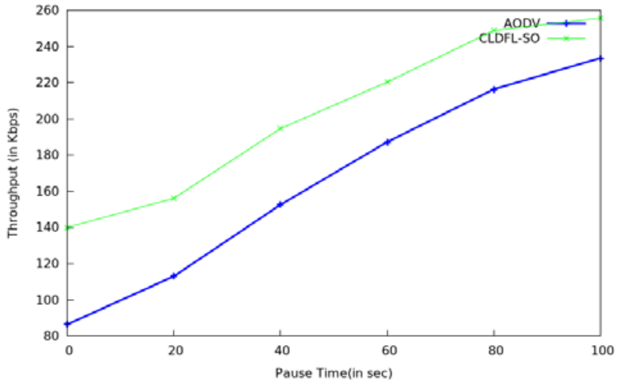

Fig.15. Pause Time vs Throughput

Performance studies and simulations show that the proposed CLDFL-SO routing protocol adapts efficiently to the MANET's dynamic behaviour. Additionally, it constantly increases the overall performance of the network when compared to conventional AODV routing, as packets are communicated via a stable route rather than a shorter route.

5. Conclusion

Developing a stability-oriented routing protocol for MANETs is an important task to improve the network lifetime. However, developing of this kind routing protocols has proven to be extremely difficult due to the inherent characteristics of such networks. In our paper, the CLDFL-SO routing protocol for MANETs is introduced, which explores a stable route rather than a shorter route, as the overhead imposed by a link failure is significantly more than the overhead imposed by the longer route. In classical AODV, the route selection is done based on the minimum number of hops regardless of the node quality as well as link stability used in the route formation, thus it suffers the frequent link failure. The outlined CLDFL-SO routing protocol excludes unstable link and low-quality node during the formation of the route; in this way, an attempt has been made to eliminate the drawbacks of the traditional AODV routing protocol. The stability of the link is evaluated by cross-layer interaction parameter (*RSSI*) based on link residual lifetime estimation. To evaluate the node quality, this protocol uses node speed, residual energy and node degree as an input to the fuzzy inference engine.

After rigorous simulation analysis key benefits of CLDL-SO routing protocol is the following.

- It minimizes the network traffic by reducing the unnecessary flooding of RREQ packet in the network.
- It also offers better performance than traditional AODV in terms of control overhead, normalized routing overhead, end-to-end delay, packet delivery ratio as well as throughput.

In future, additional metrics will be incorporated into the fuzzy inference engine to improve the suggested protocol's efficacy.

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