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A New Robust Fuzzy Logic based Routing Protocol in MANET

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***Abstract*— A Mobile ad hoc Network or MANET is a wireless network of mobile devices that has the ability to self-configure and self-organize and is characterized by an absence of centralized administration and network infrastructure. MANETs are open to a wide range of attacks due to their unique characteristics such as dynamic topology, open medium, absence of infrastructure, multi hop scenario and resource constraint. In MANETs, each ad hoc node acts both as host and as router, thus, it must be capable of forwarding packets to other nodes. The topology of these networks, changes frequently and depend on several factors such as traffic models, node mobility and link stability. To solve this problem, special routing protocols for MANETs are needed, because the traditional routing protocols for wired networks cannot work efficiently in MANETs. In this paper, we propose a new robust routing protocol based on fuzzy logic. The proposed protocol considers the different parameters such as the distance between nodes, the velocity of neighboring nodes relative to each other, the amount of energy of each node, and hop counts for discovering the efficient route. Simulation results show that the proposed protocol has significant improvement in QoS parameters such as the end to end delay, the amount of energy consumption and packet delivery ratio in comparison to DSR and SSR routing protocols.**

***Index Terms*— MANETs, Routing Protocol, Fuzzy Logic and QoS**

I. INTRODUCTION

ROUTING and finding the optimal paths from any source to any destination is one of the most important issues that arise in any type of network. Routing in the wired and wireless networks with infrastructure which the access points are fixed, is very difficult problem and requires special thoughts and solutions. Addressing this issue in the wireless networks without any fixed infrastructure where, nodes are not fix and are moving frequently, is much more complicated and requires the additional provisions. MANET is one of the infrastructure-less networks which is the special type of wireless network, where mobile nodes or terminals are connected through wireless interfaces forming a temporary network without any fixed infrastructure or a centralized administration. In other words a MANET is a self-organized system of mobile nodes which communicate on the wireless links. The nodes may move randomly and thus the network topology may change frequently and unpredictably at any time. MANETs are open to a wide range of attacks due to their unique characteristics like open medium, dynamically changing topology, absence of infrastructure, resource constraint (memory, bandwidth, computation power etc.) and trust among nodes. The principle behind mobile ad hoc networking is multi-hop relaying, which means messages sent by source to destination are forwarded by the other nodes if destination node is not directly reachable. In other words, an ad hoc node in MANET operates as not only end terminal but also as an intermediate router. Data packets sent by a source node may be reached to destination node via a number of intermediate nodes. Thus, multi-hop scenario occurs. This kind of networks is becoming more and more important because of the large number of applications, such as: i) Personal networks: Laptops, PDA's (Personal Digital Assistants), communication equipment, etc. ii) Military applications: tanks, planes, soldiers, etc. iii) Civil applications: Transport service networks, sport arenas, boats, meeting centers, etc. iv) Emergency operations: searching and rescue equipment, police and firemen, etc.

Mobility brings fundamental challenges to the design of routing protocols in MANETs. The mobility of nodes implies that the routing protocols of MANETs have to cope with frequent topology changes and must be parsimonious of communications and processing resources while attempting to produce correct routing tables. In generally, it can be said there is no complete and standard classification for routing in ad hoc networks and different papers have presented various classifications for this type of networks [1], [2], [3]. Based on routing strategy, ad hoc routing protocols can be categorized as proactive (table-driven), reactive (demand-driven) and Hybrids. In the proactive protocols, each node has a routing table, updated periodically, even when the nodes don't need to forward any message. In the reactive protocols, the routes are calculated only when required. When a source wants to send information to a destination, it calls on route discover mechanisms to find the best route to this destination. The hybrids protocols try to use a combination of both to improve them. Figure1 illustrates a comprehensive classification of key ad hoc routing protocols [4]. Performance comparisons of

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ad hoc routing protocols have been presented in many earlier publications [4] - [9]. As shown in figure1, Based on routing protocols whether are using a hierarchical structure on nodes in the network, we can classify them into flat and hierarchical protocols. In the flat routing protocols, all nodes have the same role and use the same algorithm. The flat routing protocols are suitable for small networks. In the hierarchical routing protocols, a subset of nodes assumes more routing responsibility than other nodes. The hierarchical routing protocols are suitable for medium to large networks. The flat routing schemas are further classified into two classes: proactive and reactive, according to their design philosophy. Proactive routing protocols provide fast response to topology changes by continuously monitoring topology changes and disseminating the related information as needed over the network. However, the price paid for this rapid response to topology changes is the increase in signaling overhead, and this can lead to smaller packet-delivery ratios and longer delays when topology changes increase. In the worst case, “broadcast-storms” [25] can result in congesting the entire network. Reactive routing protocols operate on a need to have basis, and can, in principle, reduce the signaling overhead. However, the long setup time in route discovery and slow response to route changes can offset the benefits derived from on-demand signaling and lead to inferior performance. The Performance analysis and simulation results [26], [27] show that reactive protocols outperform proactive protocols in terms of packet delivery ratio, routing overhead, and energy efficiency. Based on localization capability of nodes, e.g., using GPS (Global Positioning System) devices, we can classify routing protocols into the position-based and the topology-based protocols. Assuming that we know the position of a destination node, position-based routing protocols can use greedy forwarding, i.e., sending the packets to the nodes which are closer to the destination. However, providing an efficient and scalable localization service in MANETs is difficult.

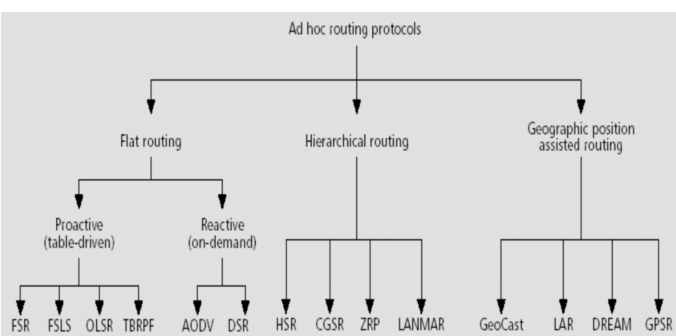


Fig. 1. Classification of ad hoc routing protocols [4]

In general, many problems in providing desired QoS parameters can be caused by diverse applications and high flexibility of ad hoc networks. QoS assurance depends on the reliable routing. In the other words, in order to achieving desired QoS, the routing based on the requested service must be provided. Therefore, in this paper, we have tried to offer an optimal and efficient routing protocol for raising route stability, increasing packet delivery ratio and improving energy consumption. The offered protocol is placed in the group of the reactive protocols.

Several research works have been presented using the fuzzy logic for routing in MANETs [13], [15]. The advantages of fuzzy logic are its simplicity, flexibility of combining conventional control techniques, ability to model nonlinear functions, imprecise information, use of empirical knowledge and dependency on heuristics. Due to the basic characteristics of ad hoc networks such as uncertainty and mobility of nodes, resource constraint and unstable links, there is not an accurate model to implement. In such an environment, fuzzy logic theory has been proved a good method for routing compared to other routing methods. Fuzzy logic can be used to solve the routing problem in ad hoc networks where the final outcome is based on the factors with uncertainty. In fact, imprecise data of network are considered realistically and consequently, the routing performance will be improved by this method.

The rest of the paper is organized as follows: Section II presents literatures review. Fuzzy logic is briefly described in Section III. The proposed routing protocol is given in section IV. The simulation results have been illustrated in Section V. The final section includes conclusions and future works.

II. LITERATURE REVIEW

A lot of routing protocols for MANETs have been proposed in the last years. The main constraint of all the existing protocols is that, they do not take into account all the QoS parameters while determining the optimal path. Most of the existing routing protocols just consider path cost and delay as the routing metrics, but in an ad hoc environment, it is actually prominent to take into account further QoS parameters while finding the optimal route. In this section, we discuss the most widely used traditional proactive and reactive routing protocols. Destination Sequenced Distance Vector (DSDV) [5] is a proactive routing protocol which is a modification of the conventional Bellman Ford routing algorithm. This protocol adds a new attribute, sequence number, to each route table entry at each node. Each node in the network maintains a routing table for transmission of packets and also for connectivity to different stations in the network. The routing entry is tagged with a sequence number which is originated by the destination station. The usage of sequence numbers provides loop freedom. In order to maintain consistency each station transmits and updates its routing tables periodically. DSDV protocol requires that each mobile station in the network, must constantly advertise to each of its neighbor, its own routing table. DSDV provides an option of route updates using the full or incremental update strategies. However, it becomes difficult to maintain routing table’s advertisements for large networks using this technique. Optimized Link State Routing (OLSR) [16] is a proactive (table driven) protocol which can be considered as an adaptation to the ad hoc network world of the OSPF (Open Shortest Path First) protocol deployed in wired internet. AODV employs periodic exchange of messages to maintain topology information of the network at each node. OLSR is an optimization over a pure link state protocol optimizing the global broadcast operation or flooding. The OLSR protocol defines the multipoint relay concept (MPR) [22] to limit the number of message retransmissions during the necessary flooding operations. OLSR works best for large and dense ad hoc networks. However, OLSR being a reactive routing protocol suffers from excessive routing overhead. Temporally Ordered Routing Algorithm (TORA) [23] is a highly adaptive, loop-free, distributed routing algorithm based on the concept of link reversal. TORA is designed to operate in highly dynamic mobile networking environment. It is source initiated and provides multiple routes for any source/destination pair. The key design concept of TORA is the localization of control messages to a very small set of nodes near the occurrence of a topological change. To accomplish this, nodes need to maintain routing information about adjacent (one-hop) nodes. During the route creation and maintenance phases, nodes use a height metric to establish a DAG (directed acyclic graph) rooted at the destination. Thereafter links are assigned a direction (upstream or downstream) based on the relative height metric of neighboring nodes. Information may flow from nodes with higher height to nodes with lower height. By maintaining a set of totally-ordered heights at all times, TORA achieves loop free multipath routing, as information cannot flow upstream and so cross back on itself. Dynamic Source Routing (DSR) [7] protocol is one of the most efficient reactive routing protocols in mobile ad hoc networks. The DSR protocol uses a process of route discovery between two network nodes when it is necessary for a specific communication. When a node wants to send a data message to another node, it searches for a route in its local cache. If no route for this terminal is found, a process of route discovery is activated in order to find the path to the destination node. The node wanting route discovery generates a route request (RREQ) control message. This control message is broadcasted to all its neighbors. This message contains the identity of the initiating node, destination node and a unique sequence number determined by the initiating node. When a node receives a RREQ message, it generates a response message, a route reply (RREP), if it is the recipient of the route request; if not, it adds its identity at the end of the intermediate nodes list and rebroadcasts this modified message over the radio interface. Ad Hoc On Demand Distance Vector (AODV) [6] protocol is a reactive protocol in which the routes are created only when required. It uses traditional routing tables, one entry per destination, and sequence numbers to determine whether routing information is up-to-date and to prevent routing hops. AODV attempts to improve on DSR by maintaining routing tables at the nodes, so that data packets do not have to contain routes. However, AODV retains the desirable features of DSR, that routes are maintained only between nodes which need to communicate. Route Requests are forwarded in manner similar to DSR. When a node re-broadcasts a route request (RREQ) it sets up a reverse path pointing towards the source. AODV assumes symmetric (bi-directional) links. When the intended destination receives a Route Request, it replies by sending a route reply(RREP). Route reply travels along the reverse path set-up when route request (RREQ) is forwarded. Zone Routing Protocol (ZRP) [24] provides a hybrid proactive/reactive routing framework in an attempt to achieve scalability. In ZRP, the network is divided into zones. A proactive table driven strategy is used for establishment and maintenance of routes between nodes of the same zone, and a reactive on demand strategy is used for communication between nodes of different zones. When a destination is out of the zone, on-demand routing search is initiated. In this situation, control overhead is reduced, compared to both the route request flooding mechanism employed in on demand protocols and periodic flooding of routing information packet in table driven protocol. The above discussed routing protocols have certain disadvantages such as in DSDV wastage of bandwidth occurs due to unnecessary routing. DSDV is not suitable for large networks. In DSR the packet header length grows with route length due to source routing. Increased contention occurs if too many route replies come back due to nodes replying using their local cache. This is also known as the Route Reply Storm Problem. Stale caches also lead to increased overhead. Although AODV being an efficient protocol than DSR has a few disadvantages. Intermediate nodes can lead to inconsistent routes if the source sequence number is very old and the intermediate nodes have a higher but not the latest destination sequence numbers, thereby having state entries. Also, multiple Route Reply packets in response to a single Route Request packet can lead to heavy control overhead. Unnecessary bandwidth consumption is also prevalent in AODV due to periodic beaconing. OLSR protocol also suffers certain disadvantages such as lack of security, routing overhead and no support for multicast. ZRP being a hybrid also requires proper query control, without which ZRP can actually perform worse than most flooding based protocols. However, above mentioned routing protocols do not address issues like security, trust/reputation of neighbor nodes, energy constraints, bandwidth, congestion, etc in network. Various new routing protocols have been developed and proposed that try to overcome certain but not all limitations that exist in previous routing protocols. In continue, we study the overview of the existing fuzzy logic based routing protocols for the ad hoc networks. In the RRAF (Reliable Routing Algorithm based on fuzzy logic) [15] two parameters, trust value and energy value are defined for each node. Based on the values of these parameters, lifetime of the routes are determined. This scheme basically uses AODV for routing. At the time of route discovery, each node inserts its trust value and energy capacity in the Route Request (RREQ) packet. Fuzzy logic is used at the destination. A parameter called "Reliability value" is generated by the destination using the input trust and energy values. This reliability value is then used for routing. A path which is having greater reliability value is preferred over the others. So, this algorithm improves the performance of AODV but fails to consider the important QoS parameters except reliability and cost. SSR (Source Select Route) protocol is another fuzzy logic based routing protocols that have been exhibited in [14]. The goals of SSR protocol is in finding the optimized path between the source and the destination. Maximum distance between the nodes, maximum relative speed between the neighbor nodes and the total number of data transmission links in the intermediate nodes are the significant factors for selecting the route. The authors claimed that SSR protocol outperforms in comparison to other conventional ad hoc routing protocols. But this protocol does not consider all the QoS parameters. The FCMQR (Fuzzy Cost based Multi constrained QoS Routing) protocol[17] is based on multi criterion objective fuzzy measure. To select an optimal path, this protocol takes into account different parameters like bandwidth, number of intermediate hops and end to end delay for selecting an optimized path. All the available resources for a path are used to compute the fuzzy cost for that path. The path which is having minimum fuzzy cost and maximum lifetime is chosen as the optimal route for transmission. This protocol Fails to consider space, cost, energy level and reliability constraints. The objective of FSRS (Fuzzy based Stable Routing Scheme) [18] is to find the most stable route for routing. Therefore, it takes the number of intermediate nodes, packet queue occupancy and the distance between the nodes as the input parameters. A fuzzy controller is used by the algorithm to calculate the lifetime of the route. Route cost is used as input to the fuzzy controller. The proposed scheme considers the average end to end delay, packet delivery ratio and routing load as the metrics. FQRA (Fuzzy QoS Routing Algorithm) [19] is an extension of the Dijkstra's shortest path algorithm and uses the bandwidth and delay as the routing metrics. Improved path success ratio, improved throughput and reduced end to end delay are good features of this scheme. FLWMR (Fuzzy Logic Wireless Multi path Routing) [20] is a routing scheme that applies fuzzy logic to differentiated resource allocation, considering traffic importance and network state. Messages are routed over zero or more maximally disjoint paths to the destination. In other words, important packets may be forwarded redundantly over multiple disjoint paths for increased reliability, while less important traffic may be suppressed at the source. This decision is taken based on the importance of the packets. Since a request for data transmission comes, the route request messages are broadcasted by the source node to every other node in the network. When the request packet reaches to the destination, the path traversed by that request packet is recorded and then that path is used for transmitting the data. This protocol Considers only hop count to find the optimal route.

III. FUZZY LOGIC

Fuzzy Logic was initiated in 1965 [8], by Lotfi A. Zadeh, professor for computer science at the University of California in Berkeley. Basically, Fuzzy Logic (FL) is multivalued logic, that allows intermediate values to be defined between conventional evaluations like true/false, yes/no, high/low, etc. Notions like as rather tall or very fast can be formulated mathematically and processed by computers, in order to apply a more human-like way of thinking in the programming of computers [21]. A fuzzy logic system (FLS) can be defined as the nonlinear mapping of an input data set to a scalar output data.

Generally there are three types of fuzzy systems that are: Pure fuzzy System, Takagi-Sugeno-Kang fuzzy system and fuzzy System with fuzzifier & defuzzifier. We have used fuzzy System with fuzzifier & defuzzifier in our proposed protocol. A fuzzy System with fuzzifier & defuzzifier consists of four main parts: fuzzier, rules, inference engine, and defuzzier. The process of fuzzy logic maintains the following steps: Firstly, a crisp set of input data are gathered and converted to a fuzzy set using fuzzy linguistic variables, fuzzy linguistic terms and membership functions. This step is known as fuzzification. Afterwards, an inference is made based on a set of rules. Lastly, the resulting fuzzy output is mapped to a crisp output using the membership functions, in the defuzzification step. Fuzzification is a process where inputs are a set of fuzzy inputs and the output is crisp values.

The basic component of this type of fuzzy system has shown in Fig. 2.

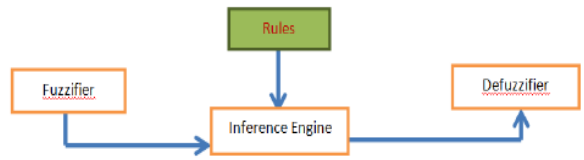


Fig. 2. The basic component of fuzzy model

The membership function of a fuzzy set, is generalized of the characteristic function in classical sets. The membership functions for each set X, is a function of X over the interval [0,1]. The membership function X is fuzzy subset X. membership function of fuzzy set $\tilde{A}$ is usually displayed as μ_A. For every member x of X, the $\mu_A(x)$ is the membership degree of x in fuzzy set A. If the membership degree of an member of the set is equal to zero, the member is fully out of the fuzzy set and if the membership degree is equal to one, it means that the member is quite in fuzzy set. However, if the membership degree of a member is a number between zero and one, this number represents the membership degree is gradual. The membership functions, are classified to the types of point, linear and nonlinear. The linear type is derived from geometric polygon shapes and is represented as dashed polygon, trapezoid, rectangle, triangle, L-shaped and S-shaped membership functions. The non-linear type is derived from the inverted forms and is shown as Gauss, P , L-shaped and S-shaped membership functions, respectively. in Figure3 shows the membership function of a fuzzy set.

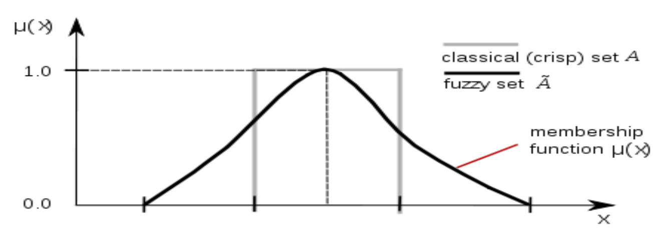


Fig. 3. The membership function of a fuzzy set

IV. PROPOSED ROUTING PROTOCOL

A. Route Discovery Protocol

As mentioned in section1, we have applied fuzzy logic applications to propose efficient routing protocol that it leads to raising route stability coefficient, increasing packet delivery ratio and improving energy consumption. In proposed protocol, a unique identification number is assigned to each node and nodes in the network is known as {node1, node2, ..., node k}. If nodes i and j are placed into sight radio communication, the Lij link is created between them. Each node uses a device to calculate it's position, a receiver to collect external signals which are used to analyze and determine the position. Global Positioning System (GPS) is The simplest way to positioning, which consists of 24 satellites in six circular orbit Equivalent of 10,900 nautical miles around the Earth at an angle of 55 degrees in a 12-hour period [9], [10]. The position and velocity of each node is calculated according to (1) , (2):

$$P_i = X_i + Y_i \qquad (1)$$

$$V_i = V_{Xi} + V_{Yi} \qquad (2)$$

If a source node wants to send data to a destination node, the task of routing algorithm is to find an appropriate route to communicate. Route discovery process, is started with the broadcasting of a route request packet (RREQ) by the source node. In Fig. 4, the RREQ packet is shown.

Packet Type =1 (1 byte)	Source address No (1 byte)	Destination address No (1 byte)	RREQ-Nc (1 byte)	Hop Count (1 byte)	Intermediate node address (Max 20 byte)	RREQ Time Gen(3 byte)	TTL (1 byte)
Stack Pointer (4 byte)	Intermediate node Velocity (Max 20 byte)	Intermediate Node Remain Energy (Max 20 byte)					

Fig. 4. Route request packet

The neighboring nodes by receiving the RREQ packet add their information and rebroadcast it. When the destination node receives the first RREQ packet, activates a timer and generates a RREP packet for each received RREQ packet in the time interval between receiving first RREQ until the timer is expired. The generated RREP packet is sent to the source node in the path traversed by corresponding RREQ packet. Figure5 illustrates the structure of RREP packet. Moreover, to prevent the additional broadcasting of RREQ packets at the intermediate nodes while the timer is expired, a dead time parameter is adjusted by destination node and is added to the RREP packet. The intermediate nodes compare their current time with the destination timer, if the current time have been greater than the destination timer then the intermediate nodes destroy the received RREQ packets in that time interval. Finally, The source node by using several factors such as position and velocity information of nodes, node's remain energy and traffic information, can compute the Route stability Coefficient (RSC) and the Route Robustness Coefficient (RRC).

B. *Link Stability Coefficient*

Since mobile ad hoc network topologies is determined based on several factors such as traffic models, node mobility and link stability thus, considering just one or two parameters in specifying the optimal route is not enough. Hence, in the proposed protocol, we have used two fuzzy logic systems so that work together and consider more parameters to select the best route. In Fig. 6, a block diagram of the proposed fuzzy logic system, is shown. The system output is Route-Robust coefficient.

Packet Type = 2 (1Byte)	Source address No (1 byte)	Destination address No (1 byte)	RREQ-No (1 byte)	RREP counter (1byte)	Hop Count (1 byte)	Intermediate node address (Max 20 byte)	RREP Time Gen(3 byte)	Rreq Time Gen (3 Byte)
TTL (1 byte)	Stack Pointer (4 byte)	Intermediate node X location (Max 20 byte)	Intermediate node Y location (Max 20 byte)	Intermediate node Velocity (Max 20 byte)	Intermediate Node Velocity direction (Max 20 byte)	Intermediate Node Remain Energy (Max 20 byte)	Intermediate Node Remain Energy (Max 20 Byte)	Dead time (3 byte)

Fig. 5. Route reply packet

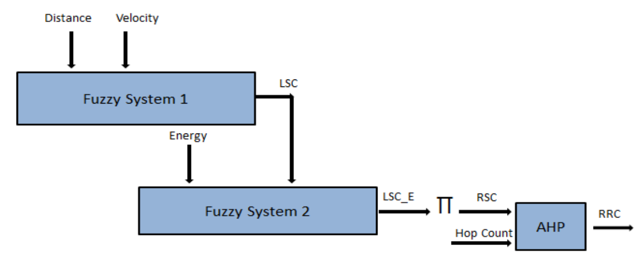


Fig. 6. The block diagram of proposed system

As can be seen in Figure6, each fuzzy system has two input parameters. Fuzzy system1, considers distance between two neighboring nodes and their relative velocity to each other as the system input and generates the link stability coefficient (LSC) as the system output. Fuzzy system2, exploits system output1 and energy of nodes as input and computes the link-energy stability coefficient. The relative velocity of the two nodes to each other is calculated by (3). When the source node receives the RREP packet, distance between the intermediate nodes is computed by using the geographic positioning of nodes and the Euclidian distance according to (4).

$$\Delta v_{i,j} = \left(v_i cos\alpha - v_j cos\beta\right) - \left(v_i sin\alpha - v_j sin\beta\right) \quad (3)$$

$$\Delta d_{i,j} = p_i - p_j = \sqrt{[(p_{xi} - p_{xj})^2 + (p_{yi} - p_{yj})^2]} \quad (4)$$

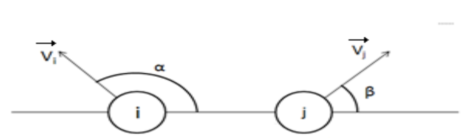


Fig. 7. Geographic position of nodes i,j

In Figure7, α and β, shows the angle between the velocity vectors vi, vj respectively. The two vectors of the same length and direction have $\Delta v_{i,j} = 0$. If the two vectors are toward each other then $\Delta v_{i,j} > 0$ and if the two vectors are in opposite direction of each other then $\Delta v_{i,j} < 0$. The block diagram of fuzzy system1 is shown in Fig. 8.

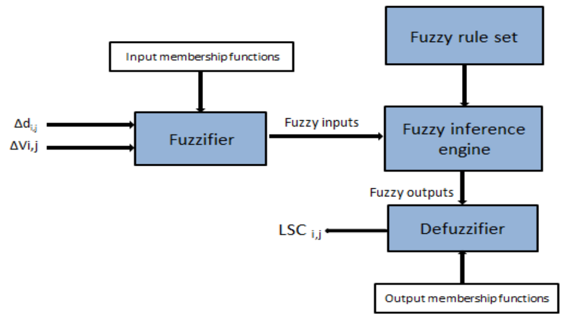


Fig. 8. The block diagram of fuzzy system1

Based on the distance value and the relative velocity of the neighboring nodes, the fuzzy rules determine the link stability coefficient value according to Table I. In Table I, for each input parameter, three Linguistic variables and for the link stability coefficient as output parameter, five linguistic variables are defined. When distance value is low and relative velocity of the two neighboring nodes is zero then the link stability coefficient has very high value. The effective membership functions which are used for computing link-stability coefficient are presented in Fig. 9.

TABLE I. REQUIRED FUZZY RULES FOR COMPUTING THE LINK-STABILITY COEFFICIENT

Distance / Velocity	Low	Medium	High
Negative	High	Medium	Low
Zero	Very_high	High	Medium
Positive	Medium	Low	Very_low

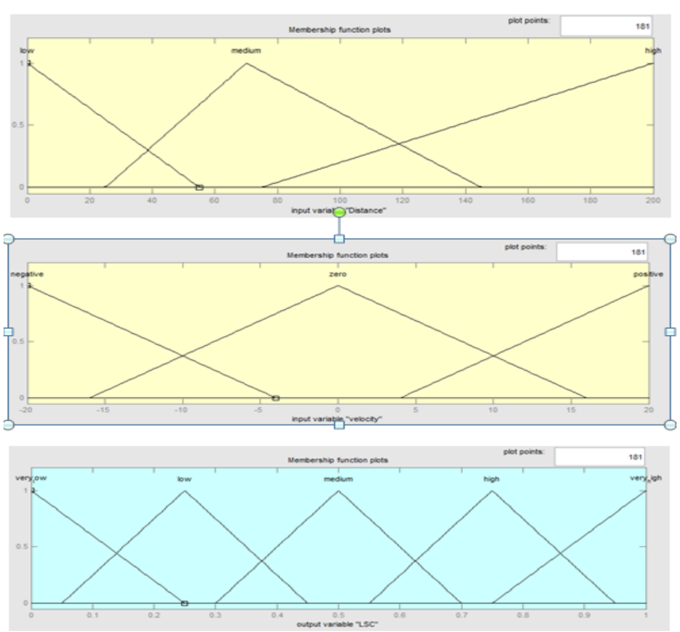


Fig. 9. The effective membership functions for computing the link stability coefficient

One of the main characteristics of mobile ad hoc networks is that the nodes have limited energy, therefore, taking into account the energy consumption in a ad hoc network has vital impact to improve QoS. Generally, calculating the energy consumption in MANETs depends on the various states of nodes, for example a node can be in send, receive and idle state and each of these states has different level of energy consumption. The energy consumption of nodes in send and receive states is calculated according to (5),(6) [11], [12].

$$Energy_{tx}=(330*5*Size(P))/2*10^6 \quad (5)$$

$$Energy_{rx}=(230*5*Size(P))/2*10^6 \quad (6)$$

In the above relations, size(p), presents the packet size. The link-energy coefficient is determined using the intermediate nodes energy and the link stability coefficient as inputs fuzzy system2. The block diagram of fuzzy system2 is illustrated in Fig. 10.

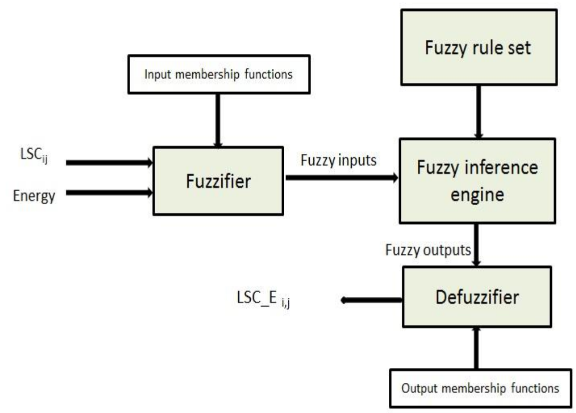


Fig. 10. The block diagram of fuzzy system2

As can be seen in Fig. 10, the relation between the link stability coefficient and the intermediate nodes energy is determined by fuzzy rules too.

TABLE II. FUZZY RULES RELATED TO CALCULATING THE LINK-ENERGY STABILITY COEFFICIENT

LSC / energy	Very_low	Low	Medium	High	Very_high
Very_low	Very_very_low	Very_very_low	Very_very_low	Very_very_low	Very_very_low
Low	Very_very_low	Very_low	Very_low	Low	Medium
Medium	Very_low	Low	Medium	High	Very_high
High	Very_low	Low	Medium	High	Very_high
Very_high	Very_low	Low	High	Very_high	Very_very_high

C. Route Stability Coefficient

The route stability coefficient is considered as multiplicative constraint and can be calculated by multiplying link-energy stability coefficients through the route. By considering the route stability coefficient in selecting the route, making the instable routes which have low lifetime is prevented. Hence, it causes to have the routes with less probability to break in during the data transmission. For example, the link-energy stability coefficient between any two nodes is shown in Fig. 12. Moreover, the route stability coefficients with assuming source node1 and destination node 8 are calculated according to Table III.

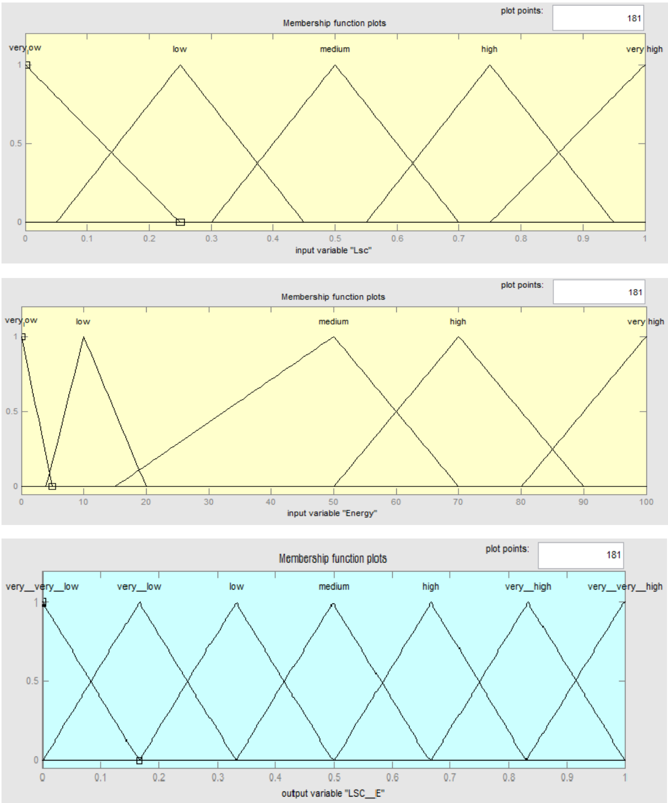


Fig. 11. The membership functions related to calculating the link-energy stability coefficient.

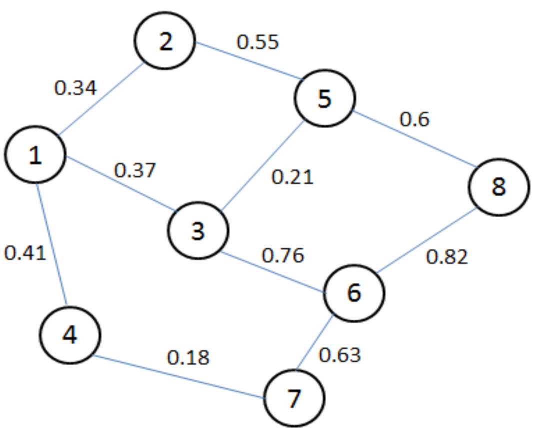


Fig. 12. The example of calculating the route stability coefficient

TABLE III. ROUTE STABILITY COEFFICIENT OF DISCOVERED ROUTES

1-2-5-8	RSC1,8 = LSC_E1,2 * LSC_E2,5 * LSC_E5,8	RSC1,8 = 0.1122
1-3-5-8	RSC1,8 = LSC_E1,3 * LSC_E3,5 * LSC_E5,8	RSC1,8 = 0.04662
1-3-6-8	RSC1,8 = LSC_E1,3 * LSC_E3,6 * LSC_E6,8	RSC1,8 = 0.23
1-4-7-6-8	RSC1,8 = LSC_E1,4 * LSC_E4,7 * LSC_E7,6 * LSC_E6,8	RSC1,8 = 0.038

D. Route Robustness Coefficient

In the most routing protocols in ad hoc networks such as AODV protocol, the minimum number of hops as the only parameter is used to select the route. In the other words in many cases, the shortest route would be the most appropriate route. Hence, in the proposed protocol, we have involved the impact of hop count parameter using a Analytic Hierarchy Process (AHP) function in the selected route apart from the route stability coefficient calculation. AHP is one of the most efficient decision making techniques and designs a system for multi-criteria decision making. This process, can be used when the act of decision making faces with multiple alternative options and decision criteria. The stated criteria can be considered Qualitative and quantitative. This decision making technique is based on paired-wise comparisons. The decision makers start with a hierarchical decision tree. The hhierarchical decision tree shows the factors to compare and evaluate competing alternatives in the decision. Then a series of paired comparisons performed. This comparisons presents weight of each factor in order to evaluate competing alternatives in the decision. Finally, the logic of AHP combines matrices of paired comparisons such that the optimal decision is obtained. In this section, by considering hop count and the route stability coefficient as decision criteria has been tried to select most robust route. The source node after receiving the first RREP packet, by doing the above steps, will start to send data packets from the selective route.Then the source node by receiving the next RREP packet, calculates the route robustness coefficient all of the routes. if exists a route that has higher robustness coefficient than the current route, the data transmission route is changed.

For example, in Figure13, we suppose nodes 1,6 are the source node and the destination node respectively. At first, source node1 starts broadcasting a RREQ packet, the intermediate nodes transmit the RREQ packet to the destination node. Table IV, represents the discovered routes between source node1 and the destination node6 and their receiving time in respect to first RREQ packet. The destination node in time period T, generates a RREP packet for every RREQ packet. According to the received RREQ packets, the destination node generates the three RREP packets (the time of receiving RREQ packet4 is out of the time period T). The intermediate nodes by receiving the RREP packet, add their information and send it to the source node. The source node receives, three RREP packets from the three different paths.

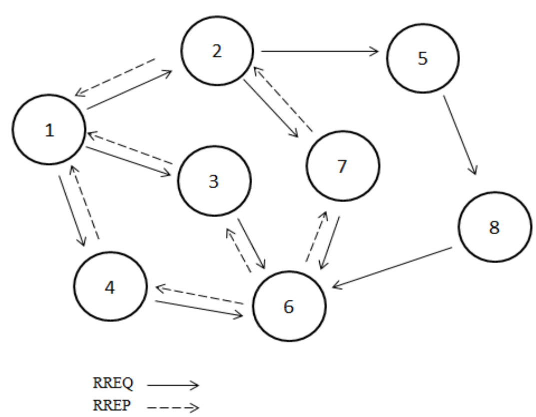


Fig. 13. The example of changing the current route in the proposed routing protocol

TABLE IV. DISCOVERED PATH

RREQ Number	Discovered path	Receive time
RREQ1	1,4,6	t_1
RREQ2	1,3,6	$t_2 - t_1 < T$
RREQ3	1,2,7,6	$t_3 - t_1 < T$
RREQ4	1,2,5,8,6	$t_4 - t_1 > T$

In Table V, the robustness coefficient of routes are shown. The source node by receiving the first RREP packet starts the data transmission from the first route and while it receives the third RREP packet with the higher route robustness coefficient, the data transmission route is switched to the third route. Flowcharts 1,2 demonstrate the route discovery process in the proposed protocol.

TABLE V. ROUTE RONUSTNESS COEFFICIENT OF EACH RREP PACKET

RREP Number	RRC
RREP 1	0.63
RREP 2	0.52
RREP 3	0.70

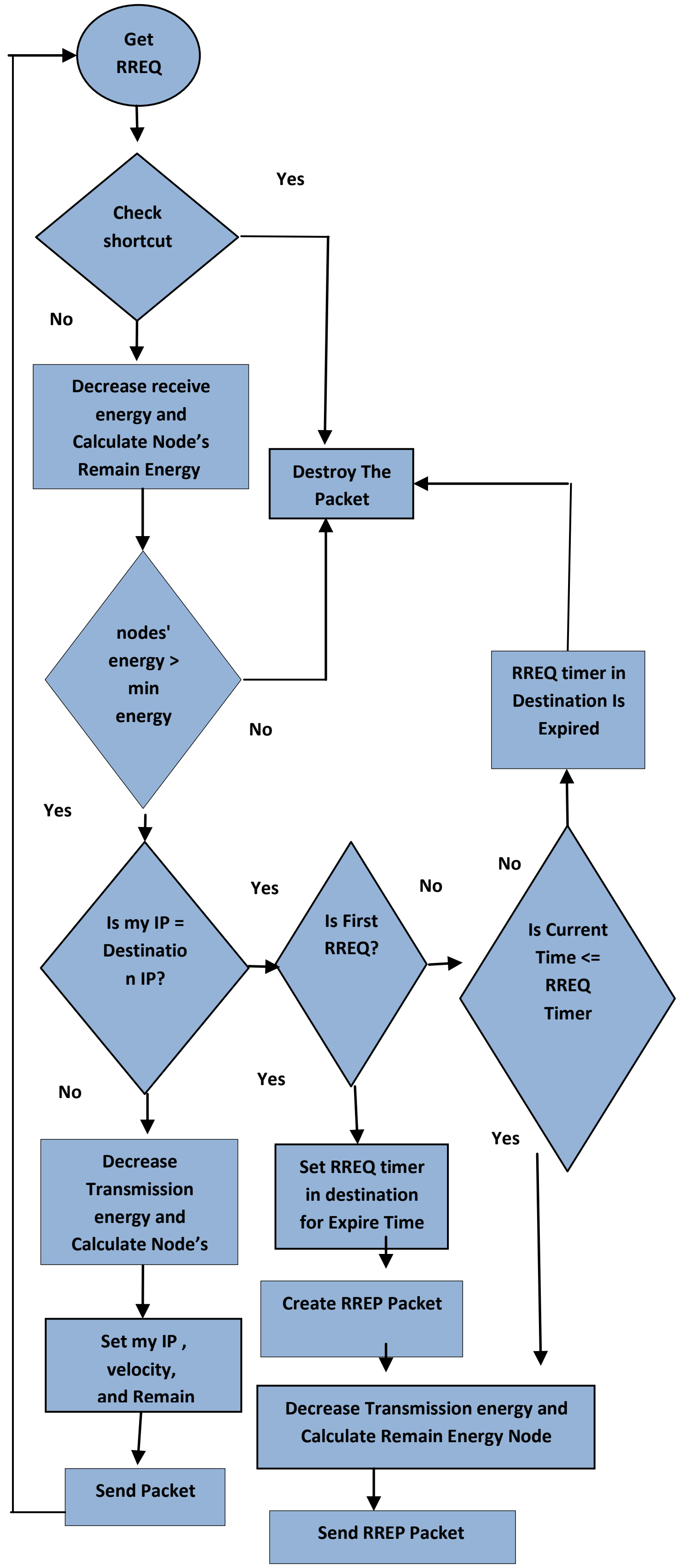
V. SIMULATION RESULTS

In this section, we evaluate the performance of our Fuzzy based Robustness routing protocol (FRR) in comparison to DSR and SSR protocols [14]. We have used OPNET simulator for simulation of MANET and our proposed routing protocol. The simulation environment consists of 50 nodes that are placed in a two-dimensional space with area of 1200×1200 square meters and the simulation time is 300 seconds. It is assumed that the nodes can move in two dimensions and the speed range is from zero to 20 meters per second. At first, the velocity of nodes is determined using a uniform distribution function at random. The used mobility model is based on Random Way Point model. In this model, each node selects a point in this space randomly and starts to move towards it. In terms of how to select a node for each point in space, Equations (7) and (8) are used. Regarding the above, 0 <Rand <1, that is, a random number with uniform distribution. The nodes move towards the selective point according to (9). In the other words, for each node can be considered a mobile step and then euclidian distance between the previous and the next it's position is calculated.

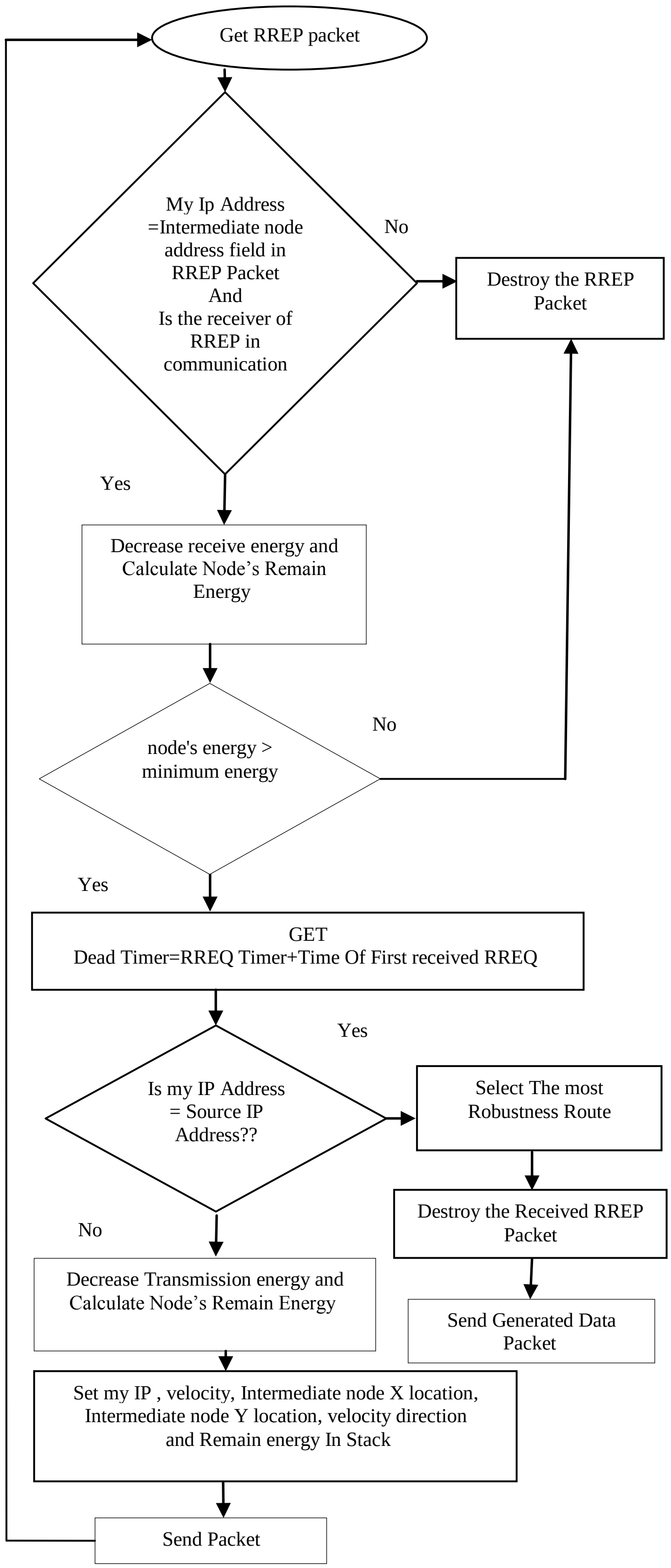
$$X_2 = 1000 \times Rand \tag{7}$$

$$Y_2 = 1000 \times Rand \tag{8}$$

$$\Delta d = \sqrt{(x_2 - x_1)^2 + (y_2 - y_1)^2} \tag{9}$$



Flowchart 1. The operation of intermediate nodes during the route request packet in the proposed protocol



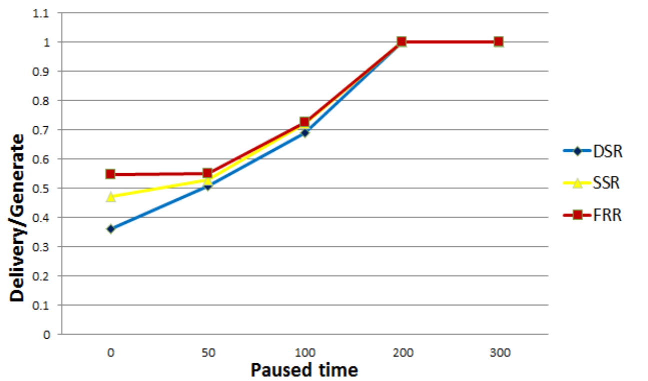
Flowchart 2: The operation of intermediate nodes during the route reply packet in the proposed protocol

For determining the effectiveness of the route robustness coefficient in selecting the route, we assume the paused times of nodes are 0, 50, 100, 200, 300 seconds respectively. Zero paused time means, after moving nodes from the first point to the second point, they begin to move immediately towards the next selection. When the paused time is equal to 300 seconds all of the nodes are considered fixed in the duration of simulation time. The communication radius of nodes is 150 meters. That is, if the distance between two nodes is less than 150 meters, two nodes can communicate with each other. The node channel bandwidth is given 2Mbps and the size of packet is 4096Bit. The traffic model that is used in this simulation is such that are generated 10 packets in per second, and a route request packet in per 10 seconds. Other simulation parameters are shown in TABLE VI. One of the evaluation parameters that we have used in our experiment is PDR parameter that is calculated as, the ratio of the average received packets by the destination to average packets sent by the source to the destination. The end to end delay is another evaluation parameter that we have mentioned.

TABLE VI. SIMULATION PARAMETERS

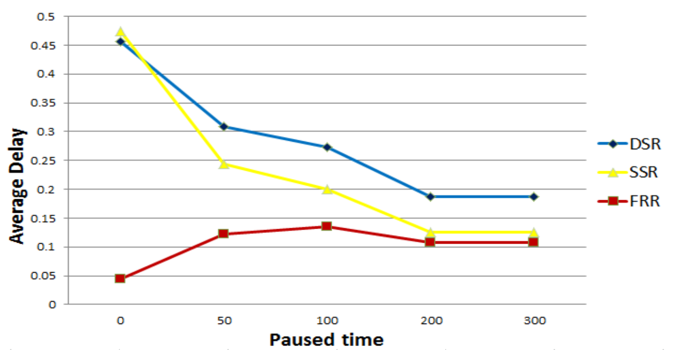
Value	**Simulation parameters**
50	Number of nodes
1200*1200	Network size(m)
300	Simulation duration(sec)
150	Communication Radius(m)
Random way point	Mobility Model
2	Channel Bandwidth (Mbps)
4096	Packet Size (Bit)
Node-23	Source node
node-4	Destination node
Constant(0.1)	Data Packet Inter-Arrival Time(sec)
Constant(10)	Rreq Packet Inter-Arrival Time(sec)
0-300	Node Paused Time(Sec)

In our simulation, we have considered two scenarios. At first scenario, we show the changes of PDR parameter value and average end-to-end delay parameter in terms of the mobility of nodes and nodes energy. The simulation results are shown in Fig. 14 and Fig. 15. As can be seen in Fig. 14, our proposed protocol have higher PDR value than DSR and SSR protocols, especially in paused time 0 that nodes are moving quite. Fig. 15 illustrates the average end to end delay in our proposed protocol has significant improvement in comparison to DRS and SSR protocols.



DSR	0.36191762	0.50844024	0.69074949	1	1
FRR	0.54625253	0.55097907	0.72518569	1	1
SSR	0.47130317	0.53072248	0.72383525	1	1

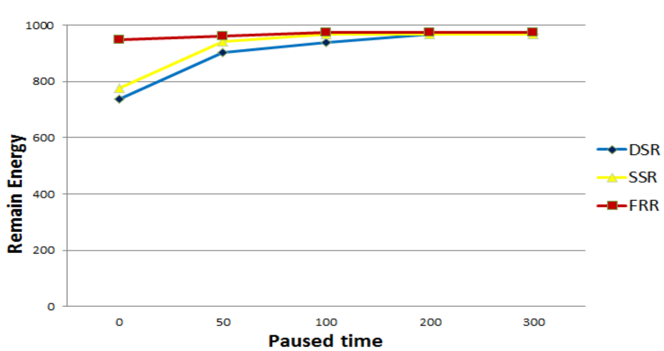
Fig. 14. PDR values with regard to the mobility of nodes and nodes energy



DSR	0.45689678	0.30942766	0.27232615	0.1866375	0.1866375
FRR	0.04380978	0.12266718	0.13562676	0.1076437	0.1076437
SSR	0.47363576	0.24395236	0.20029254	0.12535878	0.12535878

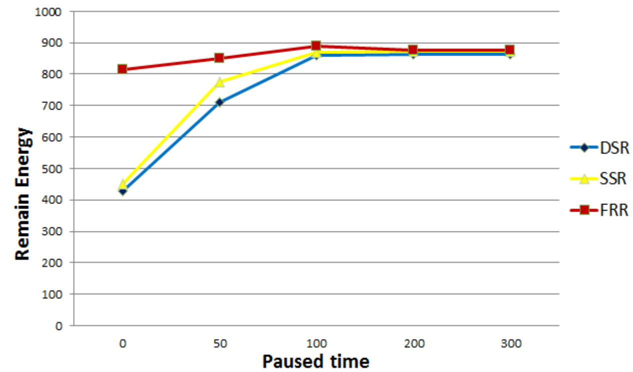
Fig. 15. The average end to end delay with regard to the mobility of nodes and nodes energy

The average and minimum remaining energy of nodes with initial energy1,000 joules are demonstrated in Fig. 16 and Fig. 17.



DSR	736.64764	901.62283	939.56983	969.38107	969.38107
FRR	947.84827	960.6874	974.21927	973.57344	973.57344
SSR	777.19765	941.57525	969.41648	969.35755	969.35755

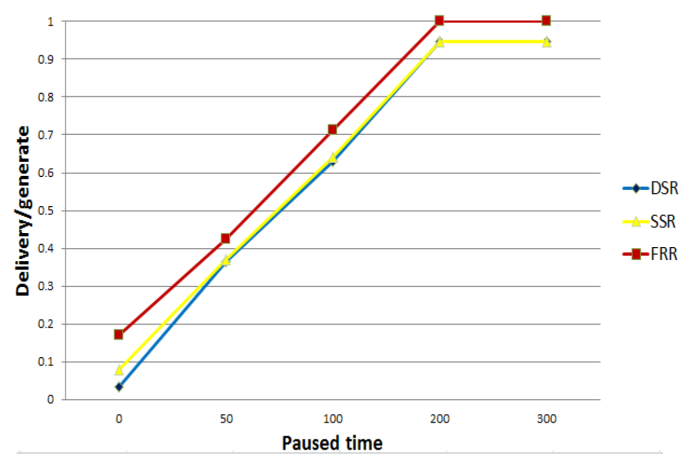
Fig. 16. The average remaining energy of nodes in the network



DSR	427.8464256	710.740608	858.8667648	864.0345088	864.0345088
FRR	813.2586496	851.0414848	889.1554816	876.219904	876.219904
SSR	449.646592	777.1113472	869.4817792	874.1402112	874.1402112

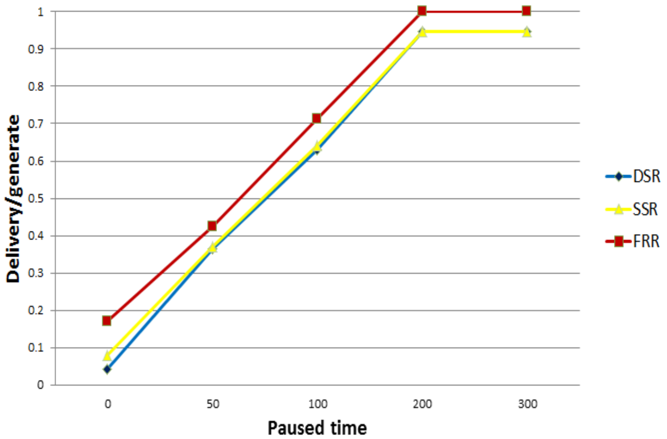
Fig. 17. The minimum remaining energy of nodes in the network

At second scenario, we examine our proposed protocol in the critical circumstances. Therefore, we choose three nodes of network which play most significant role in routing and decrease their energy to 30 joules in fail times 9, 19, 29, respectively. Fig. 18 to Fig. 20 illustrate the changes of PDR parameter in terms of the mobility of nodes and the times in which the energy of a few selective nodes is decreased to 30 joules.



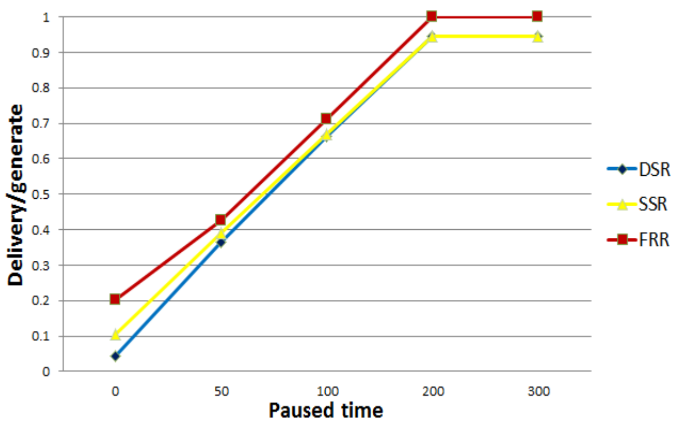
DSR	0.03443619	0.3646185	0.62997974	0.94665766	0.94665766
FRR	0.16948008	0.42471308	0.71235652	0.99932478	0.99932478
SSR	0.07494936	0.37069548	0.64280891	0.94665766	0.94665766

Fig. 18. PDR values in fail time=9



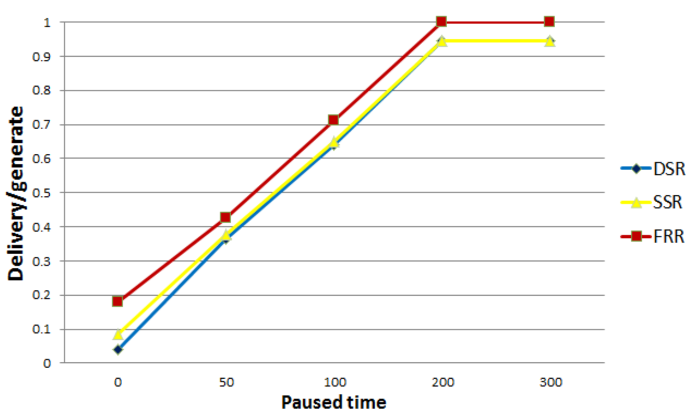
DSR	0.04321404	0.3646185	0.62930452	0.94665766	0.94665766
FRR	0.16948008	0.42471303	0.71235652	1	1
SSR	0.07896624	0.37069548	0.64213369	0.94665766	0.94665766

Fig.19. PDR values in fail time=19



DSR	0.04321404	0.3646185	0.6630655	0.94665766	0.94665766
FRR	0.20189061	0.42471303	0.71235652	1	1
SSR	0.1049919	0.39069548	0.66914247	0.94598244	0.94598244

Fig. 20. PDR value in fail time=29

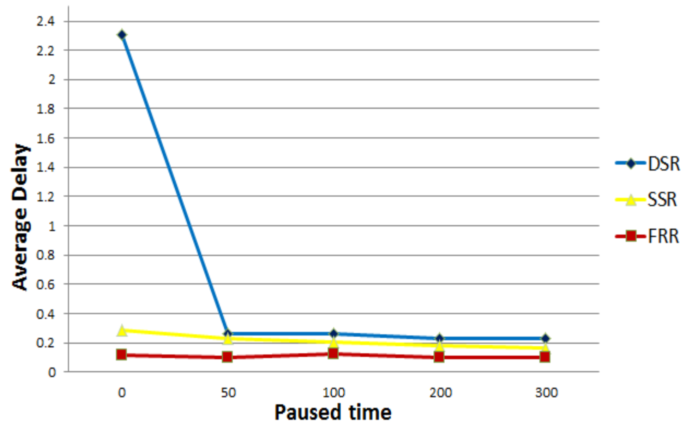


DSR	0.04028809	0.3646185	0.64078325	0.94665766	0.94665766
FRR	0.18028359	0.42471303	0.71235652	0.99977493	0.99977493
SSR	0.0863025	0.37736214	0.65136169	0.94643259	0.94643259

Fig.21. The average of PDR in fail times=9,19,29

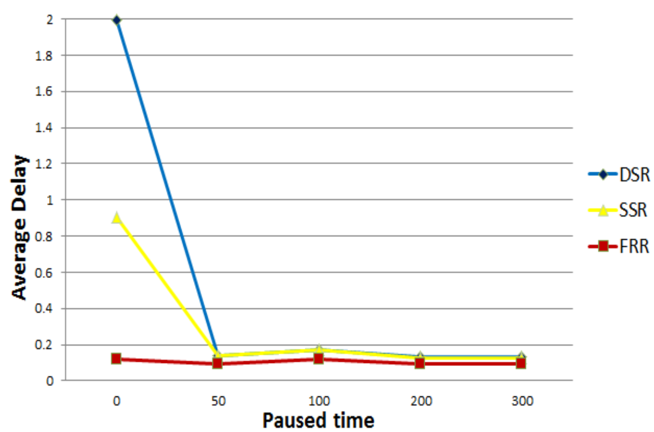
In Fig. 21, the average of PDR is calculated. As can be seen in figure 21, by increasing the paused time, the number of path failures is reduced. Also it can be found, by considering the energy parameter besides the route stability coefficient, proposed protocol prevents the establishment of unstable routes and reduces the runtime of the route discovery process in compared to the SSR and DSR protocols.

The average end to end delay is another evaluation parameter that we mention in second scenario. Fig. 22 to Fig. 24 show the results in different fail times. Also Fig. 25 illustrates proposed protocol have the least average end to end delay in zero paused time.



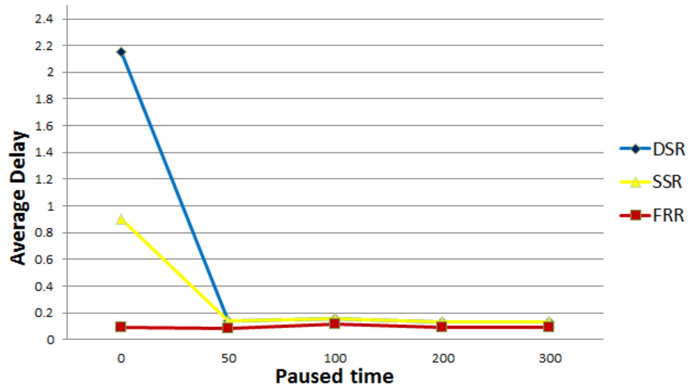
DSR	2.31063005	0.14107308	0.1716881	0.12998863	0.12998863
FRR	0.11815394	0.10250556	0.12677435	0.09858119	0.09858119
SSR	0.2892731	0.22741156	0.20868617	0.18481255	0.16481255

Fig. 22. The average end to end delay in fail time=9



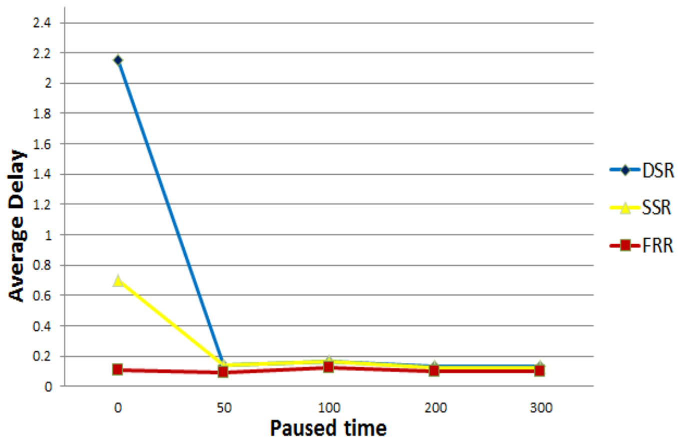
DSR	1.99771373	0.14107308	0.17383231	0.13225456	0.13225456
FRR	0.11870062	0.09177529	0.12043899	0.09467424	0.09467424
SSR	0.9050535	0.13741156	0.17051478	0.12687683	0.12687683

Fig. 23. The average end to end delay in fail time=19



DSR	2.15170701	0.14107308	0.15864689	0.13460367	0.13460367
FRR	0.09293399	0.08175695	0.11446597	0.09457234	0.09457234
SSR	0.9038695	0.13741156	0.15327599	0.1289411	0.1289411

Fig. 24. The average end to end delay in fail time=29



DSR	2.1533503	0.1410731	0.1680558	0.1322823	0.1322823
FRR	0.1099295	0.0920126	0.1205598	0.0959426	0.0959426
SSR	0.6993987	0.1374116	0.164159	0.1268768	0.1268768

Fig. 25. The average end to end delay in fail times=9,19, 29

VI. CONCLUSION

A lot of routing protocols for MANETs have been proposed in the last years. The main constraint of all the existing protocols is that, they do not take into account all the QoS parameters while determining the optimal route. Most of the proposed routing protocols consider just path cost and delay as the routing metrics, but in an ad hoc environment, it is actually prominent to consider extreme QoS parameters while finding the optimal route. In this paper, we have proposed a new robust routing protocol based on fuzzy logic. The proposed protocol considers the different parameters such as the distance between nodes, the relative velocity of neighboring nodes to each other, the amount of energy of each node, and hop count for discovering the efficient route. Simulation results show that the our proposed protocol has significant improvements in QoS parameters such as the end to end delay, the amount of energy consumption and packet delivery ratio in comparison to DSR and SSR routing protocols. The potential area for the future research can be the identification of more parameters which can lead to the enhancement of QoS, improvement in routing as well as increase in their lifetimes.

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