Dynamic and Reactive Multi-Objective Routing Decision in Position-based Routing Protocols

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Abstract
Current greedy routing protocol (GFS) designed to find shortest path as a single routing objective. Considering only one routing objective is insufficient for the computation of a reliable rout, and can severely compromise network performance on the remaining overlooked objectives. This paper introduces the Dynamic and Reactive Reliability Estimation with Selective Metrics Mechanism (DRESM). The intended DRESM is constructed of two coherent techniques; the Fuzzy Logic Dynamic Nodes' Reliability Estimation (FLDRE) and the Status Information Distribution and Outgoing Traffic Control Management (IDOTM). FLDRE introduce the notion of multi-criteria next relay node selection using fuzzy weighted logic multi-objectives. IDOTM provides the sender node with fresh information about its neighbour and control the outgoing traffic. The simulation results show that DRESM outperforms GFS in terms of packet delivery ratio, average end-to-end delay. Moreover, DRESM can find routs whose cost is close to the optimum.

Index Terms
Greedy routing protocol, Dynamic and reactive reliability estimation with selective metrics mechanism, Fuzzy logic dynamic nodes' reliability estimation, Status information distribution and outgoing traffic control management

1. Introduction

A Mobile Ad Hoc Networks (MANETs) is a self-organizing multi-hop wireless network where all nodes participate in the routing process [1]. With MANET, arbitrarily motions of mobile nodes introduce a frequent and an unpredictable change in network topology [2]. The used routing protocol is one of the most issues influence the performance and reliability of MANET [3]. Such routing protocols need to work well not just with law mobility and small network. But also, we need more dynamic routing protocol that responds quickly to high mobility, frequent topology changes, and optimally using MANET limited recourses [4].
Position-aware routing protocols are rapidly gaining reputation in the context of MANET over topology based routing protocols [5]. Position-based routing protocols are stateless, hence, it is not necessary to create and maintain a global route from the sender to the destination [6]. Therefore, position-based routing protocol prevents extra overhead to be occurred [7]. Also, it prevents latency of route discovery incurred by traditional topology based routing protocols [8].
Current GFS algorithm tries to achieve a single routing objective, which is shortest path (SHPA) [9]. SHPA approach usually results in fast response for route setup with the minimum hops number (optimal rout) [10]. However, the GFS algorithm has a high probability that traffic concentrates at the center of the network that incurs Hot Spot Phenomenon (HSPH) [11].
The Hot Spot nodes tend to carry more traffic because they often used as relay nodes, and therefore transmission is congested [12]. In congested traffic areas, packets have high probability to be dropped due to the fixed length of interface queues [13]. Moreover, the existence of hot spot problem forces the nodes at the central area to have more traffic to forward and die quickly due to out of battery power [14]. As a consequence of those dead nodes a link failure occurs. Once a link failure occurs at this relay node, all connections passing through this node suffer [15]. On the other hand, nodes located at other areas of the network are far from saturated.
MANET system, characterized by limited and precious resources and thus, just using SHPA that incurs HSPH can significantly harm MANET efficiency [16]. To alleviate the HSPH problem, this work deals with two concerns. The former one is how to further distribute the load among the nodes. The latter one is how to choose the next hop node i.e. what are the criteria to be considered to select the next rely node.
To address the first concern, this work aims to explore and exploit the unused system resources. Thus, research is underway to balance the traffic load evenly. The system resources at the edge of the network, which are only lightly used, could be used more efficiently. Meanwhile, less congestion in the middle leads to a smaller number of collisions and thus the efficiency in the middle area of the network can be significantly increased, thereby improving system performance.

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In order to distribute traffic effectively, more system information is required to help routing protocols select the appropriate next relay node. This goal can be achieved by locally and reactively providing every participating node with comprehensive and accurate information about its neighbours, and thus, the network resources are allocated more efficiently.

To address the second concern, it is clear that GFS satisfy one objective when it uses a single metric to define the best cost path. In general, routing objectives in MANETs are not completely independent; an improvement in one objective can only be achieved at the expense of others. Thus, to improve the efficiency of GFS routing and to distribute traffic load, selection process should be based on selecting the next relay node that meets multiple objectives. Multiple routing objectives can be met together only if multiple routing metrics that give detailed information on the state of the intermediate nodes are considered.

However, GFS routing protocol forward the data, node by node, and packet by packet. Thus, one of the main benefits of using GFS includes its ability to weight individual next hop choices according to additional metrics. Routes can be altered node by node and packet by packet simply by considering additional metrics relating to the next hop neighbours, such as their congestion level, their connectivity degree etc. Therefore geographic forwarding in this basic form offers an effective solution to routing in MANETs.

In this paper, we developed multiple criteria approaches that can optimize several metrics simultaneously. We proposed the fuzzy logic modified greedy routing (FLDRE) technique for unicast routing in mobile ad hoc networks. The fuzzy logic weighted multi-criteria of the protocol is used to dynamically evaluate the reliability index of the node's neighbours to determine the most optimal next relay node. Moreover, to provide the sender node with full information about its neighbours, FLDRE is combined with Status Information Distribution and Outgoing Traffic Control Management (IDOTM) technique. By using the IDOTM, sender node can easily be provided by fresh information about its neighbours through using the four handshaking messages. Both techniques are integrated to shape the Dynamic and Reactive Reliability Estimation with Selective Metrics Mechanism (DRESM). Proposed DRESM replace the selection process in the conventional GFS.

In addition to the above introduction, the reminder of this paper is organized as follows; next section presents the proposed routing metrics for DRESM, followed by DRESM design architecture and objectives in Section III. First technique IDOTM of DRESM presented in Section IV, followed by second technique FLDRE in Section V. Before concluded this work in Section VII, the performance analysis of the proposed DRESM is presented in Section VI.

2. DRESM Design Architecture and Objectives

The overall goal of DRESM is to dynamically collect information about a node's neighbours and to estimate the reliability index of those neighbours based on five proposed metrics. By achieving this goal, the performance of routing protocols under study will be thoroughly improved. Moreover, the traffic load is distributed evenly and the constructed rout between any two communicating nodes will consist of the most reliable nodes in the direction of final target (optimal rout).

DRESM is constructed in a manner that efficiently and effectively considers and satisfies MANET constrains. The intended DRESM is constructed of two coherent techniques; the Fuzzy Logic Dynamic Nodes' Reliability Estimation (FLDRE) and the Status Information Distribution and Outgoing Traffic Control Management (IDOTM). With FLDRE the proposed fuzzy controller is used to dynamically evaluate the reliability index of the node's neighbours based on the proposed metrics. Moreover, IDOTM provides the sender node with fresh information about its neighbours and control the outgoing traffic. The details design of DRESM mechanism shown in Models Architecture as depicted in Figure 2 bellows.

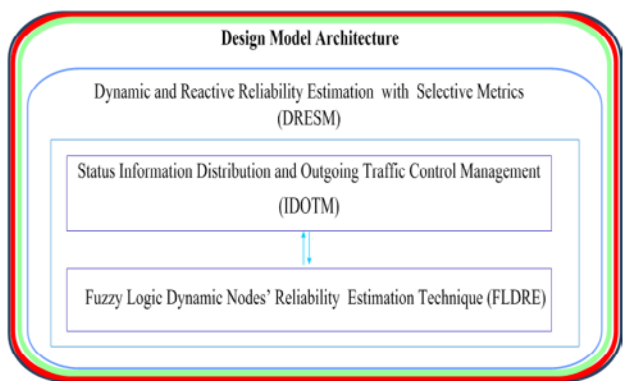


Fig. 1. DRESM model architecture details

3. Status Information Distribution and Outgoing Traffic Control Management

The Status Information Distribution and Outgoing Traffic Control Management IDOTM is designed to perform two critical processes. The former on is distribute the neighbours' status information which should be communicated between sender node and its neighbours. The latter one is to control the outgoing traffic based on the locally estimated reliability values by sender node.

To perform communication between the participating nodes, this research uses Distributed Coordination Function (DCF) which is the fundamental MAC technique of the

IEEE 802.11. The sender node should find out the reliability index of three candidate nodes to make forwarding decision. The sender does this to leverage on one of the two suboptimal nodes as next relay node when the optimal node fails to forward the packet. To accomplish this, the three nodes should receive the sent packet by sender node at the same time. This means that with the IDOTM technique, there is a need to use broadcast and unicast at the same time. The problem appears here is that the RTS/CTS/DATA/ACK mechanism of the IEEE 802.11 is only designed for unicast.

With IDOTM, the work described in [17-19] is adopted. In this work, DATA packet is transmitted as unicast and multiple receptions are achieved using MAC interception. With IDOTM and to benefit of both broadcast and unicast, the packet is sent as unicast in network layer to the optimal node as the next relay node. Simultaneously, when the packet is sent, the neighbours in the transmission range of the sender node deliver the data packet to the upper layer.

A. IDOTM architecture and Design Goal

The proposed IDOTM technique consists of four messages. First message is the Request To Forward message (RTF). The RTF message is initiated by sender node. Second message is the Clear To Forward message (CTF). The CTF is generated by candidate nodes as a response to RTF message. The CTF message is initiated by the node that obeys some pre-specified conditions. And lastly, the (ACK) packet which is generated by optimal node and after it received the third message which is (DATA) packet from the sender node.

The exchange of RTF and CTF packets prior to the DATA packet is a sign to the need for medium reservation. The RTF and CTF packets hold a duration field that defines the period of time that the medium is to be reserved to transmit the actual DATA packet and the returning ACK packet.

IDOTM functions are executed on need-base. One objective of exchanging the IDOTM messages is to discover the candidate nodes in the sender node rang. Moreover, another objective is to rich the sender by fresh information about the candidate nodes to make routing decisions. The last objective is to control the outgoing traffic based on the locally estimated reliability values by sender node.

With the proposed IDOTM technique, some alterations is done for MAC as proceeded, and thus, the contention problem between participating nodes for accessing the shared wireless channel is resolved by using a Carrier Sense Multiple Access mechanism with Collision Avoidance (CSMA/CA). The Request To Forward and Clear To Forward (RTF/CTF) are adopted to minimize delay from collisions and hidden nodes. And thus, by using the proposed IDOTM technique the robustness of the improved routing protocol can be significantly enhanced.

In this research work, the packet transmission scenarios have been altered for the MAC layer address filter. All neighbours in a node's transmission range might deliver the packet that has been sent using MAC interception. With such alterations, this work made full utilisation of the CSMA/CA, which is supported by 802.11 MAC. Furthermore, sender nodes benefit from both broadcast and unicast simultaneously.

A node that wants to transmit the DATA packet must be free for a Distributed Inter Frame Space (DIFS). DIFS is used for the asynchronous DATA service sake. DIFS is equivalent to Short Interframe Space (SIFS) Time plus double time of Slot-Time. Typically, SIFS-Time and Slot-Time are fixed per PHY layer, these intervals set to 10 μs and 20 μs respectively, and thus, DIFS was set as 50 μs.

To generalise those rules for a number of positive and candidate neighbours, as the sender node gets the number of positive neighbours, it calculates the required waiting time to receive CTF packet from up to maximum three of them (candidate neighbours). In this work, each CTF packet is jittered by 50% of the SIFS interval. Thus, the waiting time in microseconds, to receive CTF packet from candidate neighbours, is equivalent to the time needed to send CTF multiplied by the number of candidate neighbours plus the number of candidate neighbours multiplied by 1.5 SIFS. The time for each candidate neighbour to send CTF packet is uniformly distributed in [0.5 SIFS multiplied by the number of candidate neighbours, 1.5 SIFS multiplied by the number of candidate neighbours]. The waiting time in microseconds, to receive ACK packet from all candidate neighbours is equivalent to the time to send one ACK packet plus the number of candidate neighbours multiplied by SIFS. The time for each candidate neighbour to send ACK packet is calculated incrementally (i.e. optimal node needs 1 SIFIS; 1st sub-optimal node needs 2 SIFS, etc.).

Based on the dissection above, we can generalise NAV duration time and other related periods time as follow:

$$T_{ACTF} = [(T_{CTF} * N_{cn}) + (N_{cn} * 1.5 * SIFS)]\ \mu s \quad (1)$$

$N_{cn} = 1$ in case next relay node is the destination, or the sender node has one candidate node.

$$T_{AACK} = [(T_{ACK}) + (N_{cn} * SIFS)]\ \mu s \quad (2)$$

$$NAV_{RTF}^{1} = T_{DATA} + T_{ACTF} + T_{AACK}\ \mu s \quad (3)$$

This equation is used in case sole DATA packet transmission.

$$NAV_{CTF} = NAV_{RTF} - T_{ACTF}\ \mu s \quad (4)$$

$$NAV_{ACK} = NAV_{CTF} - T_{DATA}\ \mu s \quad (5)$$

$$NAV_{RTF}^{4} = 4 * (T_{DATA} + T_{ACTF} + T_{AACK})\ \mu s \quad (6)$$

This equation is used in case 1 main transmission plus 3 retransmission of the DATA packet if the next relay node is not the destination node.

$$NAV_{RTF_{S-C}} = 4 * (T_{DATA} + T_{ACK})\ \mu s \quad (7)$$

where, T_{ACTF} is the total time required to receive all CTF from all candidate nodes, T_{AACK} is the total time required to receive one ACK from one of the candidate nodes, N_{cn} is the number of candidate neighbours, T_{DATA} is the time needed to send the DATA packet, T_{CTF} is the time required to send the one CTF packet, T_{ACK} is the time required to send the ACK packet. NAV_{RTF} total channel's reservation time to send one packet, NAV_{CTF} is total reservation time to send one CTF and one DATA and one ACK packet from each candidate nodes. NAV_{ACK} is total channel's reservation time to send one ACK packet from one of the candidate nodes.

4. Proposed routing metrics for DRESM

As it alluded to in the previous section, the Mobile Ad Hoc Greedy Fuzzy Routing FLDRE scheme is designed to achieve multi-objectives while selecting a next relay node. The different objectives that are considered for next relay node selection are to (i) maximize packet delivery ratio; (ii) minimize end-to-end delay; (iii) distribute the traffic load evenly and thus maximize the lifetime of the network, and (iv) increase the opportunity to forward the data packet using optimal rout. The proposed metrics are inspired from the works presented in [20-23]. Based on the selected resources, this work adopts five metrics to make routing decision. As illustrated in Figure 1 bellow, the proposed metrics that have been selected to meet the intended objectives are: (i) Neighbours Distance to Destination, (ii) Residual Links Lifetime, (iii) Unoccupied Buffer Length, (iv) Residual Battery Power, and (v) Next-rely Node Positive Degree.

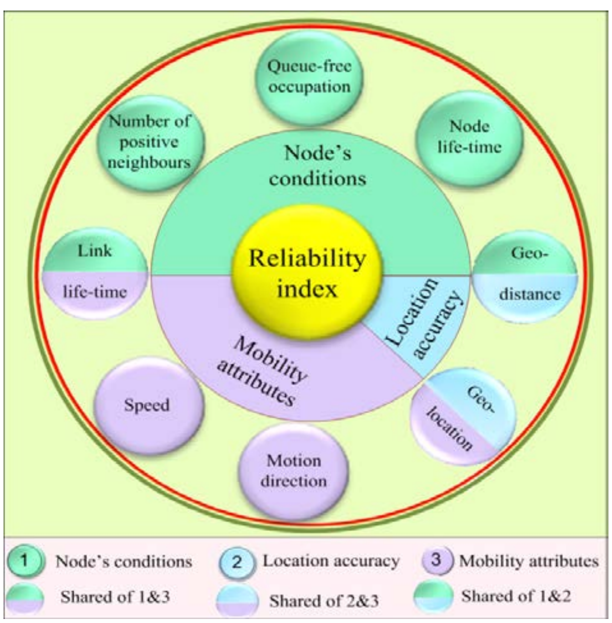


Fig. 2. Formation of selected metrics

B. Distance to Destination Identification

Distance to Destination is the popular traditional metric used with GFS as selection metric. Distance metric benefit in reducing the number of hops between source and destination. This work assumes that location information of all mobile nodes can be identified by using GPS receivers. The location information is used to calculate the distance between any two nodes.

Suppose sender node S needs to calculate the distance between candidate node C and destination node D at time t_s, it use the Pythagorean theorem formula as follows in Equation 8.

$$des_D^C\left(\left(x_{t_s}^C, y_{t_s}^C\right)\left(x_{t_s}^D, y_{t_s}^D\right)\right) = \sqrt{\left(x_{t_s}^C - x_{t_s}^D\right)^2 + \left(y_{t_s}^C - y_{t_s}^D\right)^2} \quad (8)$$

To normalize candidate nodes' distance to destination, sender node subtracts its distance to destination from each candidate distance to destination and divides the result on its transmission range (R is same for all nodes) as shown in Equation 9 bellow.

$$ð_C^S(t_s) = \begin{cases} \frac{des_D^S - des_D^C}{R}, des_D^S \geq des_D^C \\ \frac{\left|des_D^S - des_D^C\right|}{R}, \quad des_D^S < des_D^C \end{cases} \quad (9)$$

where, $ð_C^S(t_s)$ is the distance ratio of each candidate node at time t_s, des_D^S is the distance between the sender and the destination nodes, des_D^C is the distance between each candidate and destination nodes, $\left(x_{t_s}^C, y_{t_s}^C\right)\left(x_{t_s}^D, y_{t_s}^D\right)$ are the (x,y) coordinates of both nodes, and R is the transmission range.

C. Motion Speed and Direction

Mobility metrics in MANETs affect the performance of its underlying routing protocols. Among these metrics, node's movement speed and direction are two of the most critical metrics. If next relay node has high difference in speed and\or direction in comparison with sender node, then packet loss probability is increased due to unstable link. This inspires us to take both motion's direction and speed into consideration when selecting optimal next hop. With this research, a trade-off between speed and direction as a velocity vector is used. By using this trade-off, the packet sender, selects next relay node using residual link lifetime metric besides the other metrics. A mathematical model detail is introduced in the following Section.

D. Residual Links Lifetime

The link duration of a routing path is limited to any single node's link age selected as a member of this path. Thus, link lifetime between communicating nodes is one of the important issues to be considered in routing algorithm. In this work the link lifetime between two communicating nodes named as Residual Links Lifetime (RLT).

To estimate the RLT between the two nodes, work presented in [24] was adopted with some alteration, as shown in Equation 10 bellows.

$$RLT_j^i(t) = \left(\frac{\left(R - \sqrt{(x_t^i - x_t^j)^2 + (y_t^i - y_t^j)^2} \right)}{\sqrt{(v_t^i \cos\theta_t^i - v_t^j \cos\emptyset_t^j)^2 + (v_t^i \sin\theta_t^i - v_t^j \sin\emptyset_t^j)^2}} \right) \quad (10)$$

where, $RLT_j^i(t)$ is the residual lifetime of the link between node i and node j at time t, R is the transmission range of the nodes, v_i and v_j are the velocity of nodes i and j respectively, θ and $\emptyset$ are the motion direction of nodes i and j respectively, $(x_t^i, y_t^i)(x_t^j, y_t^j)$ are the (x,y) coordinates of both nodes.

To map RLT range to [0,1], as a normalization process, the following formula in Equation 11, is used.

$$\Im_j^i(t_s) = \frac{(x - \min\{0.0125s, 125\})}{(\max\{0.0125s, 125\} - \min\{0.0125s, 125\})} \quad (11)$$

Where, $\Im_j^i(t_s)$ is the normalized value of the relative velocity magnitude between the nodes *i*, and *j* at time *t*.

The value $\Im_j^i$ of any neighbour is considered as an indicator for the reliability level of communication via this node. Thus, nodes are fully connected if the $\Im_j^i$ is 1 and likely out of transmission range of each other if the $\Im_j^i$ is 0.

E. Unoccupied Buffer Length

Queue size is a property of MANETs' nodes. Usually, the queue size is limited to a few packets, and nodes start to drop packets when the queue is full [25]. The queue length is considered as an indicator for the congestion level of the neighbour.

For optimal usage of network resources nodes' buffers should be uniformly used and several nodes alone should not be overused. By achieving this goal, congestion in the centre area of MANETs could be decreased, leading to fewer collisions, and saving nodes' energy as well. Thus, the efficiency of GFS is improved.

A node's unoccupied buffer length (f_{bl}) can be determined as a function varies with time. The f_{bl} can be designated based on the size of data packets currently buffered to the nod's buffer size. In this research the buffer size for all mobile nodes is assumed to be equal. And thus, a node's f_{bl} can be estimated using the Equations 12, as bellows.

$$f_{bl}^C(t_s) = T_{Buffer\ size}^C - O_{ccupied}^C(t_s) \quad (12)$$

Where, $f_{bl}^C(t_s)$ is the unoccupied buffer length at time t_s, $T_{Buffer\ size}^C$ is the total buffer size of node C, and $O_{ccupied}^C$ is the occupied buffer at time t_s.

The high value of neigbour's f_{bl}^C gives an indicator for the high reliability value of communication via this neigbour. To normalize the unoccupied length, a candidate node uses the Equation 13, as bellows.

$$\varphi_c(t_s) = \frac{(f_{bl}^C(t_s) - \min\{0, T_{Buffer\ size}^C\})}{(\max\{0, T_{Buffer\ size}^C\} - \min\{0, T_{Buffer\ size}^C\})} = \frac{f_{q\,t_s}^{\ c}}{T_{Buffer\ size}^C} \quad (13)$$

The node is fully congested if the φ_c ratio is 0, and far from congested if the ratio is 1. In order to distribute traffic effectively, each neighbour sends the level of its φ_c to the source/forwarder node, to help it to select the appropriate next relay node with preference given to less congested neighbour.

F. Residual Battery Power

In MANETs, the node's resources are limited in terms of several aspects. Mobile nodes depend on finite battery sources, and thus, power consumption is one of the most critical issues. In MANETs, the battery power consumed for the communication is higher or comparable with energy consumed by the processor [26]. However, with conventional GFS approach, the batteries of certain nodes at the centre of MANETs may drain out even though there are many nodes with plenty of energy, such that it disables further information delivery and induces packet loss and more delay.

To build an optimal route between two communicating nodes, and to solve the problem, a part of the proposed work is to be as energy- adaptive. The intermediate nodes with a high value of the remaining battery lifetime should be preferred to those with a lower value.

A node's residual battery ratio (b_{po}) can be determined as a function varies with time. The b_{po} can be designated based on the ratio between the instant consumed node's battery power to the nod's total battery energy size. In this research, the battery power for all mobile nodes is assumed to be equal. A node's residual battery power statues b_{po} can be calculated using Equations 14.

$$b_{po}^C(t_s) = Tb_{po}^C - Cb_{po}^C \quad (14)$$

where, $b_{po}^C(t_s)$ is the residual battery energy at time t_s, Tb_{po}^C is the total battery energy size of node C, and Cb_{po}^C is the consumed battery power size up to time t_s.

Thus, high values of neigbour's b_{po} gives an indicator for the high reliability value of communication via this neigbour. To normalize the nodes' residual battery power statues, a node uses Equation 15, as bellow.

$$\vartheta_C(t_s) = \frac{(b_{po}^C(t_s) - \min\{0, Tb_{po}^C\})}{(\max\{0, Tb_{po}^C\} - \min\{0, Tb_{po}^C\})} = \frac{b_{po}^C(t_s)}{Tb_{po}^C} \quad (15)$$

The node is fully battery energy if the ϑ_C ratio is 1 and likely out of energy if the ratio is 0.

G. Next-rely Node Positive Degree

A node degree is defined by how many other nodes can be reached from this node at a given moment [27]. However, for the connectivity sake of the MANET a part of it considered as a disconnected part or an isolated, in the case that some nodes do not have neighbour in any direction. These types of nodes can result in degraded network performance.

The goal here is to achieve a route between source and destination nodes in which none of the rout members is isolated. Regarding to nodes mobility, a node's positive neighbours (NPC) could be any value in the range from 0 to the node degree at time t_s $(TN^C_{degree}(t_s))$ [0, $TN^C_{degree}(t_s)$].To normalize the NPC, a node uses Equation 16, as bellow.

$$\varkappa_C(t_s) = \frac{(\mathrm{NPC}(t_s) - \min\{0, TN^C_{deg}(t_s)\})}{(\max\{0, TN^C_{deg}(t_s)\} - \min\{0, TN^C_{deg}\})} = \frac{\mathrm{NPC}(t_s)}{TN^C_{deg}} \qquad (16)$$

The node is sufficient if the $\varkappa_C$ ratio is 1 and insufficient if the ratio is 0.

5. Dynamic Reliability Estimation using Fuzzy Logic

In the literature, Fuzzy method is one of the most suited systems to be used in MANET. Fuzzy logic controller (FLC) is a process of decision making based on input membership functions and a group of fuzzy rules. In this paper, FLC is applied for finding out the reliability index of each candidate node, based on the selected 5 metrics.

In FLDRE as a FLC approach to adapt the selection process in the proposed enhancement, the 5 metrics are utilized as input parameter and reliability index (RIN) as output parameter. Figure 3 shows the FLC for FLDRE.

As shown in Figure 3, the first step of designing FLDRE is to arrange the membership functions of the input and output fuzzy variables relying on the defined range. The next is to construct appropriate rules for the FLDRE. Furthermore, the inference engine, with the aid of the proposed rules, is used to control the action in the linguistic form. Then, the fuzzy output is defuzzyfied using membership functions to generate the crisp output. The overall process involved in estimating the RIN of the candidate neighbours is elaborated in the following sub-sections.

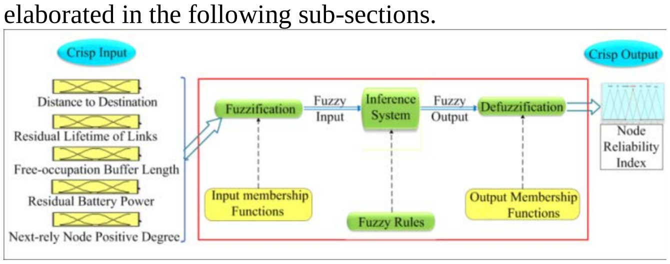


Fig. 3. Generalized fuzzy system FLC for FLDRE

H. Fuzzify Input and Output Parameters

The fuzzifier maps the crisp input values to fuzzy sets and assigns degree of membership for each fuzzy set. The 5 metrics crisp input fuzzified to 3 fuzzy sets and RIN crisp output fuzzified to 7 fuzzy sets. As suggested by [28], this research made adjacent sets to overlapp by 25% to 50%.

1) Fuzzify Selected Metrics Input

The linguistic variables used to represent the distance metric were divided into three levels: *close* (*cs*), *medium* (*md*), and *far* (*fr*); and those to represent nodes' Residual Links Lifetime, Free-occupation Buffer Length, Residual Battery Power, and Next-relay Positive Degree are divided into three levels: *low* (*lo*), *medium* (*md*), and *high* (*hi*).

Table 1 shows the assignment of names and range of the fuzzy sets for the first metric distance to destination $\eth^S_C$. Figure 4 shows the assignment of range and degree of membership functions for the first metric distance to destination $\eth^S_C$. Also, Table 2 shows the assignment of names and range of the fuzzy sets for the others 4 metrics. Figure 5 shows the assignment of range and degree of membership functions for the others 4 metrics. Hence, the $\eth^S_C$, $\Im^S_C$, φ_c, ϑ_c, and $\varkappa_c$ is fuzzified between *min-value* = zero and *max-value* = 1.

TABLE I Fuzzy Sets of $\eth^S_C$ Input Variable

$\eth^S_C$ range	Fuzzy sets	Symbol
0.035-0.45	Far	*fr*
0.08-0.92	Medium	*md*
0.55 0.965	Close	*cs*

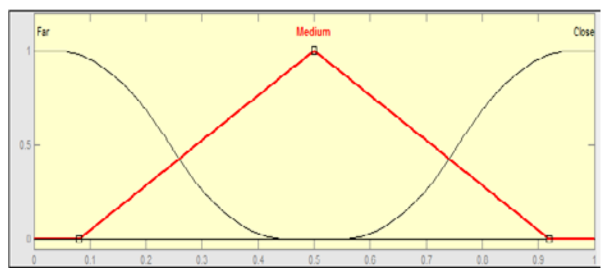


Fig. 4. Membership functions of $\eth^S_C$ input variable

TABLE II Fuzzy Sets of $\Im^S_C$, φ_c, ϑ_c, and $\varkappa_c$ Input Variables

Range	Fuzzy sets	Symbol
0.035-0.45	Low	*lo*
0.08-0.92	Medium	*md*
0.55 0.965	High	*hi*

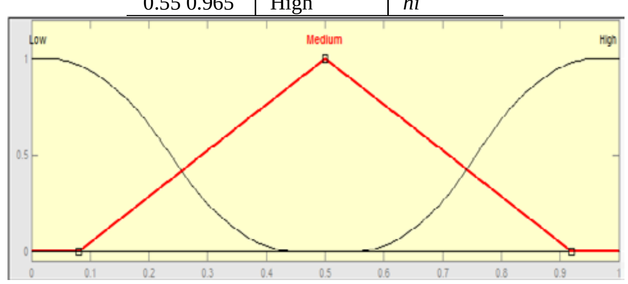


Fig. 5. Membership functions of $\Im^S_C$, φ_c, ϑ_c, and $\varkappa_c$ input variable

The explicit formulae are the same for all selected metrics, as an example, the explicit formulae for $\eth^S_C$ membership functions are given in the following:

$$ð^{S}_{C\,fr} = \begin{cases} 1, & x \le 0.035 \\ 1 - 2\left(\frac{x-0.035}{0.45-0.035}\right)^2, & 0.035 \le x \le \frac{0.035+0.45}{2} \\ 2\left(\frac{x-0.45}{0.45-0.035}\right)^2, & \frac{0.035+0.45}{2} \le x \le 0.45 \\ 0, & x \ge 0.45 \end{cases} \quad (17)$$

$$ð^{S}_{C\,md} = \begin{cases} \left(\frac{x-0.08}{0.5-0.08}\right), & 0.08 \le x \le 0.5 \\ \left(\frac{0.92-x}{0.92-0.5}\right), & 0.5 \le x \le 0.92 \\ 0, & otherwise \end{cases} \quad (18)$$

$$ð^{S}_{C\,cs} = \begin{cases} 0, & x \le 0.55 \\ 2\left(\frac{x-0.55}{0.965-0.55}\right)^2, & 0.55 \le x \le \frac{0.55+0.965}{2} \\ 1 - 2\left(\frac{x-0.965}{0.965-0.55}\right)^2, & \frac{0.55+0.965}{2} \le x \le 0.965 \\ 1, & x \ge 0.965 \end{cases} \quad (19)$$

2) Fuzzify Reliability Index Output

The consequent (the possibility that a node will be selected) was divided into 7 levels, i.e. Fuzzy sets for the RIN output variable have the following names: *very bad* (*vb*), *bad* (*bd*), *not acceptable* (*na*), *acceptable* (*ac*), *good* (*gd*), *very good* (*vg*), and *perfect* (*pt*). Table 3 and Figure 6 show the assignment of rang and membership functions for output RIN variable respectively. Hence, the RIN is fuzzified between RIN -*min* = zero and RIN -*max* = 1.

TABLE III Fuzzy Sets for RIN Output Variable

RIN range	Fuzzy sets	Symbol
0.0 - 0.25	Very bad	RIN_{vd} (R_1)
0.125 - 0.375	Bad	RIN_{bd} (R_2)
0.25- 0.5	Not acceptable	RIN_{na} (R_3)
0.375- 0.625	Acceptable	RIN_{ac} (R_4)
0.5 - 0.75	Good	RIN_{gd} (R_5)
0.625- 0.875	Very good	RIN_{vg} (R_6)
0.75– 1.0	Perfect	RIN_{pt} (R_7)

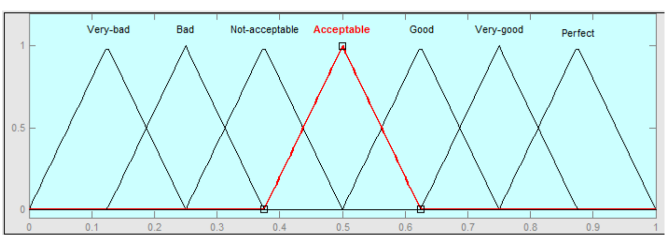


Fig. 6. Membership functions for RIN output variable

The explicit formulae for RIN membership functions are given in the following:

$$RIN_{vd} = \begin{cases} \left(\frac{x-0.0}{0.125-0.0}\right), & 0.0 \le x \le 0.125 \\ \left(\frac{0.25-x}{0.25-0.125}\right), & 0.125 \le x \le 0.25 \\ 0, & otherwise \end{cases} \quad (20)$$

$$RIN_{bd} = \begin{cases} \left(\frac{x-0.125}{0.25-0.125}\right), & 0.125 \le x \le 0.25 \\ \left(\frac{0.375-x}{0.375-0.25}\right), & 0.25 \le x \le 0.375 \\ 0, & otherwise \end{cases} \quad (21)$$

$$RIN_{na} = \begin{cases} \left(\frac{x-0.25}{0.375-0.25}\right), & 0.25 \le x \le 0.375 \\ \left(\frac{0.5-x}{0.5-0.375}\right), & 0.375 \le x \le 0.5 \\ 0, & otherwise \end{cases} \quad (22)$$

$$RIN_{ac} = \begin{cases} \left(\frac{x-0.375}{0.5-0.375}\right), & 0.375 \le x \le 0.5 \\ \left(\frac{0.625-x}{0.625-0.5}\right), & 0.5 \le x \le 0.625 \\ 0, & otherwise \end{cases} \quad (23)$$

$$RIN_{gd} = \begin{cases} \left(\frac{x-0.5}{0.625-0.5}\right), & 0.5 \le x \le 0.625 \\ \left(\frac{0.75-x}{0.75-0.625}\right), & 0.625 \le x \le 0.75 \\ 0, & otherwise \end{cases} \quad (24)$$

$$RIN_{vg} = \begin{cases} \left(\frac{x-0.625}{0.75-0.625}\right), & 0.625 \le x \le 0.75 \\ \left(\frac{0.875-x}{0.875-0.75}\right), & 0.75 \le x \le 0.875 \\ 0, & otherwise \end{cases} \quad (25)$$

$$RIN_{pt} = \begin{cases} \left(\frac{x-0.75}{0.875-0.75}\right), & 0.75 \le x \le 0.875 \\ \left(\frac{1.0-x}{1.0-0.875}\right), & 0.875 \le x \le 1.0 \\ 0, & otherwise \end{cases} \quad (26)$$

I. Fuzzy Rules and Fuzzy Inference

To map the fuzzy 5 metrics input sets into fuzzy RIN output sets this work proposed a set of fuzzy rules. The proposed rules are issued using the Fuzzy Inference System editor contained in the Matlab Fuzzy Toolbox.

There are 5 input variables and each consists of 3 fuzzy linguistic variables. And thus, the total is 243 rules are used (i.e. $3^5 = 243$). Bellow a part of the proposed rules is introduced.

RULE 1: IF $ð^S_C$ **is** far **AND** $\mathfrak{I}^S_C$ **is** low **AND** $\boldsymbol{\varphi_c}$ **is** low **AND** $\boldsymbol{\vartheta_c}$ **is** low **AND** $\boldsymbol{\varkappa_c}$ **is** low **THEN RIN is** $very\ bad$

RULE 2: IF $ð^S_C$ **is** $medium$ **AND** $\mathfrak{I}^S_C$ **is** low **AND** $\boldsymbol{\varphi_c}$ **is** low **AND** $\boldsymbol{\vartheta_c}$ **is** low **AND** $\boldsymbol{\varkappa_c}$ **is** low **THEN RIN is** $very\ bad$

. . . .

. . . .

RULE 243: IF $ð^S_C$ **is** $close$ **AND** $\mathfrak{I}^S_C$ **is** $high$ **AND** $\boldsymbol{\varphi_c}$ **is** $high$ **AND** $\boldsymbol{\vartheta_c}$ **is** $high$ **AND** $\boldsymbol{\varkappa_c}$ **is** $high$ **THEN RIN is** $perfect$

1) Defuzzification

Defuzzification is the final step; it refers to the way a crisp value is extracted from a fuzzy set as a representation value. There are many kinds of defuzzifiers. This research work used the Centroid method [29] for defuzzification as shown in Equation 27 bellow.

$$RIN = \frac{\sum_{j=1}^{w} x_j \cdot \mu(x_j)}{\sum_{j=1}^{w} \mu(x_j)} \quad (27)$$

where RIN is the crisp output, w is the number of rules, x_j is the element and $\mu(x_j)$ is its membership value of the output variable of each rule j.

6. Performance Analysis of The Proposed DRESM

J. Simulation Environment

The simulations are conducted using Ns2 version 2.33. The GPSR protocol is utilized as the underlying routing protocol. The nodes move according to the Boundless mobility model. The fuzzy logic system has been coded using C++. All simulation results have been averaged over 10 simulation runs (each plotted point in figures is an average of 10 simulation runs) and include 95 percent confidence interval data.

The simulation network area is rectangle of 2500 m × 2000 m, with 250m nodes' transmission range. We use the MAC layer protocol 802.11 DCF RTS/CTS. Bandwidth (Bw) set to standard value of 2 mbps. Traffic model uses Continuous Bit Rate (CBR) traffic sources. Traffic sources transmit data at a fixed data rate of 5 packets/s. Data packet size set to standard values 512 bytes and beacon packet size is 64 bytes. Node queue size set to standard size of 50 packets and node's queue uses First-In-First-Out (FIFO) policy. The simulation for each scenario is executed in a period of 1200, seconds, and to avoid the effect of initializing and ending, we only gather the data between 800s – 1000s.

K. Simulation scenarios

In our simulation environment, we compare the performance of GPSR-DRESM versus conventional GPSR. To demonstrate the robustness of the proposed algorithm we investigate three scenarios. In the first scenario, we deploy 50 nodes with fixed number of 5 flows and vary the nodes speed to 5, 10, 15, 20, 25, 30, 35, and 40 m/s. In the second scenario, the speed and flows are fixed to 20 m\s and 5 flows respectively, and vary the deployed number of nodes to 25, 50, 75, 100, 125, 150, 175, and 200. Finally, we deploy 50 nodes with fixed nodes speed to 20 m\s and vary the number of data traffics to 5, 10, 15, 20, 25, and 30 flows.

L. Performance Evaluation Metrics

In this work's simulations, we focused on selecting performance metrics that reflect the goal of the designed algorithm. And thus we select three metrics which are; Packet Delivery Ratio (PDR), End-To-End (E2E) Delay, and Routing Stretch Measurement (path length).

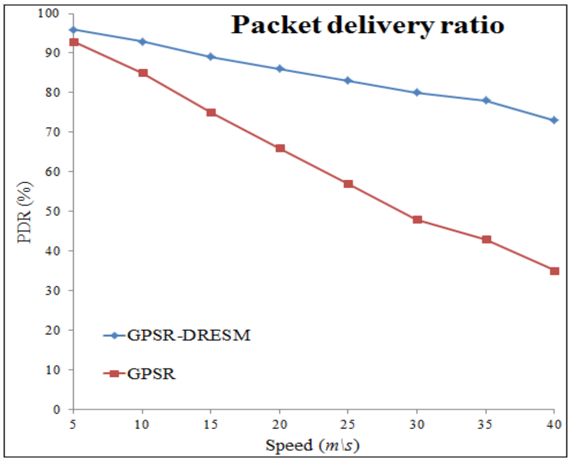
M. Simulation Results

1) Packet delivery ratio

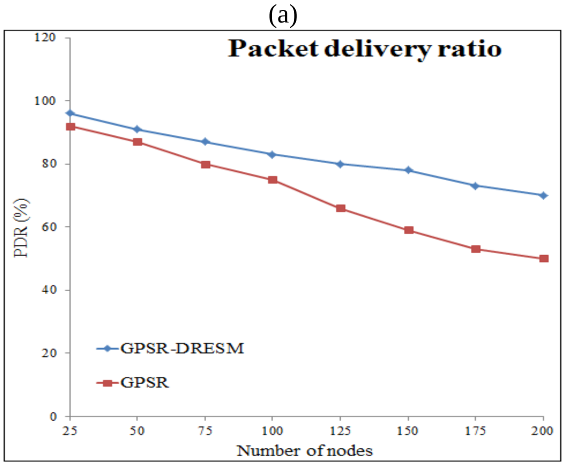
Figure 7(a) shows the performance analysis of the achieved packet delivery ratio as a function of node moving speed for the GPSR and GPSR-DRESM. Significant enhancement of Packet delivery ratio can be noticed in favor of DRESM scheme, even when speed is as high as 40m\s. Reasons for such improvement are mentioned below. Since DRESM tries to incorporate as much up to date status information of neighbours through using the four handshaking messages as possible in ad hoc networks, it suffers from much lesser link breakages compared to GPSR. And thus, GPSR-DRESM approach allowed for an increase in the delivery rate when nodes moved faster. This supports our idea of considering node mobility when making forwarding decisions With GPSR Link breakages become more frequently and increase as the node's mobility increases. This inevitably increases packet loss rate.

Figure 7(b) shows the performance analysis of the achieved packet delivery ratio as a function of the number of nodes. The figure shows that GPSR-DRESM is much better than the GPSR protocol. When using GPSR and as the a sender's degree increases the number of outdated neighbours increase too, and thus the probability to select one of these outdated neighbours as the next relay node will increase too. This incurs link brakeage to occur more frequently. With GPSR Link breakages inevitably give rise to retransmission of lost packets. This huge injection of lost packets in the network increases signal collision as well as higher congestion at the interface of neighbours. This collision and congestion incurs that percentage of packets successfully delivered to respective destinations, greatly reduce. On the other hand, with GPSR-DRESM nodes greatly benefit from the four hand shaking scheme to increase the accuracy of the selected next relay node as well as using multi-metric to select the next rely node prevent the sender node to select a congested neighbour.

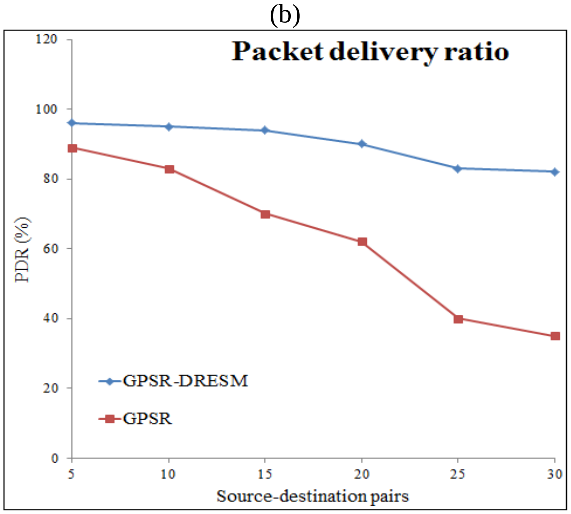
Figure 7(c) shows the performance analysis of the achieved packet delivery ratio as a function of data traffics. For both protocols, as the number of flows increases, the number of packets in the network to be rerouted increases too. With GPSR this increment in the traffic results congestion at the center of the network that increases the probability of packet loss. On the other hand, with GPSR-DRESM the main reason behind the increment in the packet rate is referred to its ability to distribute the traffic load all over the network. The result indicates that the collision and the congested are significantly decreased and thus GPSR-DRESM protocol achieves the highest packet delivery ratio.



(a)



(b)



(c)

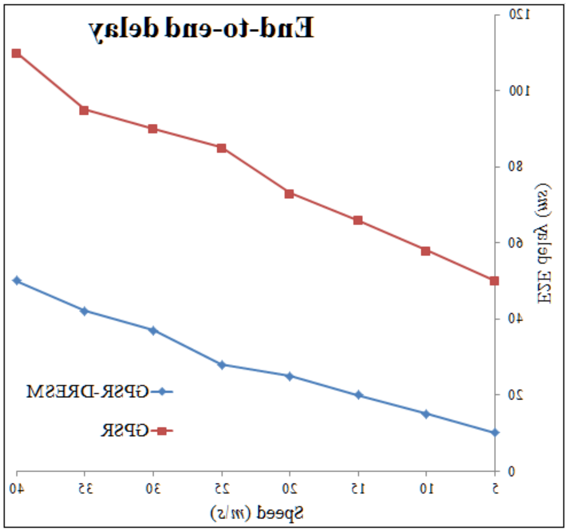
Fig. 7. Packet delivery ratio for various network settings

2) *End-To-End Delay*

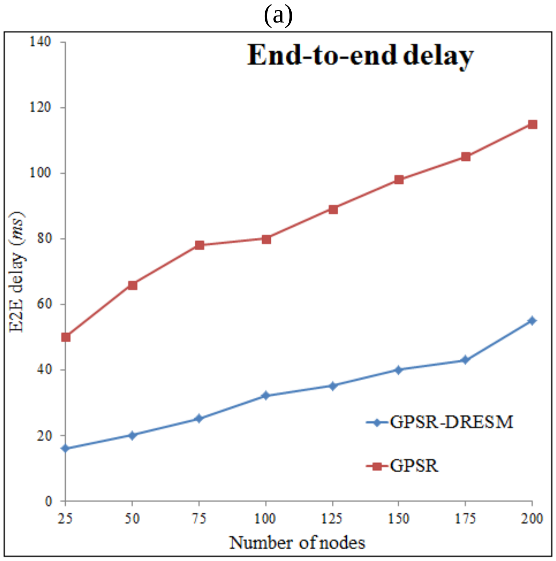
Figure 8(a) shows the average end-to-end delay in GPSR and GPSR-DRESM protocols as a function of node speed. The figure shows that GPSR-DRESM significantly decreases the average end-to-end compared to GPSR. The reason is referred to the fact that when using GPSR and as the neighbours' mobility increases the number of outdated neighbours in a sender neighbours list increase too that incurs more link breakages. With GPSR Link breakages inevitably give rise to retransmission of lost packets. Frequent link breakage and packet retransmission incurs more delay for a packet to be delivered by destination compared to DRESM. On the other hand, since DRESM tries to incorporate as much up to date status information of neighbours through using the four handshaking messages as possible in ad hoc networks; it suffers from much lesser link breakages compared to GPSR. Another main reason behind the delay decrement in GPSR-DRESM is that the proposed multi-metric scheme which integrates the next relay node positive degree has the capability of finding the shortest path around the communication hole which close to optimum compared to conventional GPSR. As the results reveal the end-to-end hops of GPSR are the largest due to the usage of perimeter mode compared to DRESM.

Figure 8(b) shows the average end-to-end delay in GPSR and GPSR-DRESM protocols as a function of the number of nodes. The figure shows that GPSR-DRESM significantly decreases the average end-to-end compared to GPSR. The reason is referred to the fact that when using GPSR and as the sender's degree increases the number of outdated neighbours increase too, and thus the probability to select one of these outdated neighbours as the next relay node is increased too. As the outdated neighbouring node is selected as the next relay one, the routed data packet is dropped. This incurs more delay to buffer the data packet during retransmission time and during selecting new next relay node. On the other hand, as the sender's degree increase while using GPSR-DRESM the sender nodes can get more accurate information about their neighbours through using the four handshaking messages. As a consequence, this prevents the sender node to send the packet to any outdated node.

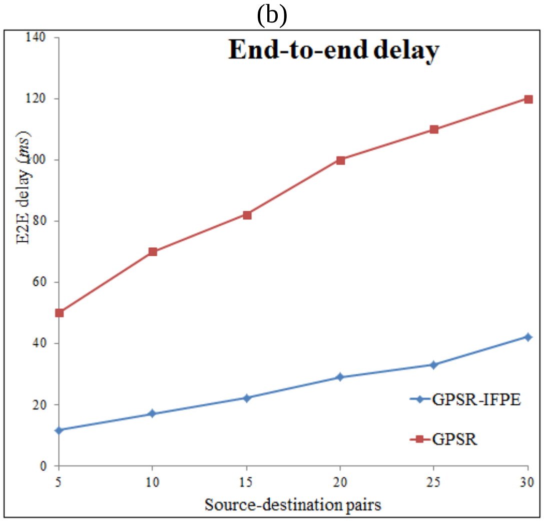
Figure 8(c) shows the average end-to-end delay in GPSR and GPSR- DRESM protocols as a function of data traffics. For both protocols, as the number of flows increases, the number of packets in the network to be rerouted increases too. With GPSR this increment in the traffic results collision and congestion at the center of the network that increases the probability of packet loss. To buffer the data packet during retransmission time and during selecting new next relay node can result in a significant longer average end-to-end delay. On the other hand, thanks FLDRE, which explicitly considers node congestion while selecting next relay node. Moreover GPSR-DRESM has the ability to distribute the traffic load all over the network. Therefore, there was less congestion, also the waited packets number at the interface of nodes queues is low, and so packets delivered by destination suffer from low delay. Thus, even with the increment of the flow GPSR-DRESM shows stability in the delay time rate.



(a)



(b)



(c)

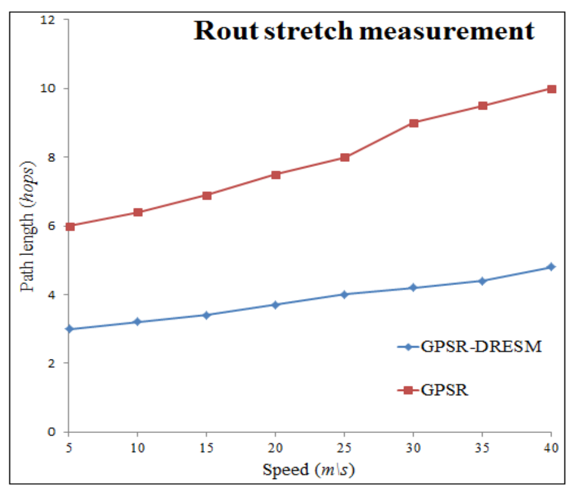
Fig. 8. End-To-End Delay for various network settings

3) Routing Stretch Measurement

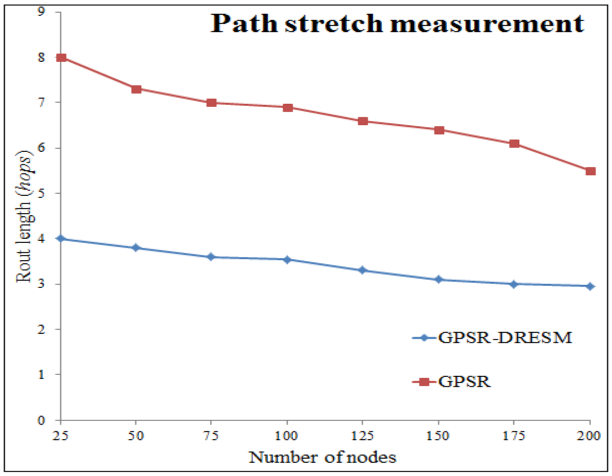
Figure 9(a) shows results for average hop count in GPSR and GPSR- DRESM protocols as the function of node speed in the network. The results shows that by increasing node mobility, conventional GPSR consumed more hop counts, while GPSR- DRESM scheme actually shortened the route and come close to optimum one. This is because GPSR- DRESM approach explicitly considers node mobility metrics in making forwarding decisions.

Figure 9(b) shows results for average hop count in GPSR and GPSR- DRESM protocols as the function of number of nodes in the network. It is obvious that for both protocols when network density increases, the average hop count for each route decreases. Also the rout length is decrease and come close to optimum. This is because both protocols can forward packet without the needed for using the recovery mode with long routs. However, using GPSR- DRESM strategy achieves better improvement in number of travelled hops compared with conventional GPSR. This is because GPSR- DRESM algorithm has the ability to select the most reliable next relay node in terms of several routing metrics.

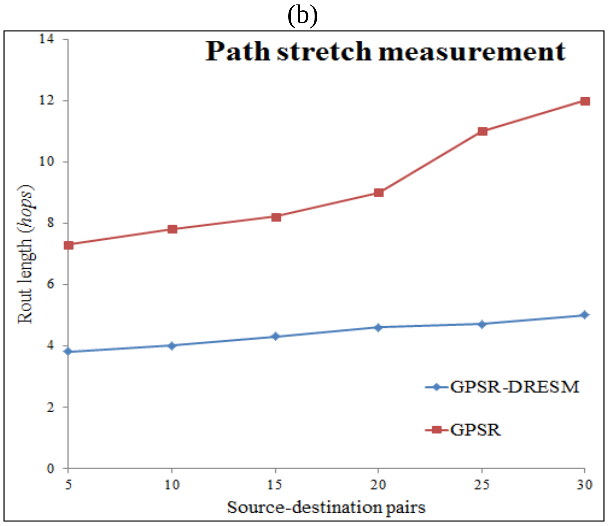
Figure 9(c) shows results for average hop count in GPSR and GPSR- DRESM protocols as the function of number of data traffics in the network. For both strategies, as the number of data traffics increase, the hop count increases this is due to more source-destination pairs involves in the routing process which yields to more packets to be forwarded. GPSR- DRESM strategy achieves better improvement in number of travelled hops compared with conventional GPSR.



(a)



(b)



(c)

Fig. 9. Routing Stretch Measurement for various network settings

7. Conclusion and Future Work

This paper investigates an evolutionary selection process in position-based routing protocol using DRESM algorithm. DRESM is composed of two sub algorithms which are; the Fuzzy Logic Dynamic Nodes' Reliability Estimation FLDRE and the Status Information Distribution and Outgoing Traffic Control Management IDOTM. FLDRE introduce the notion of multi-criteria next relay node selection using fuzzy weighted logic multi-objectives. To facilitate the detailed information collection regarding to the proposed metrics, FLDRE is supported by the IDOTM technique. The performance of DRESM has been evaluated through extensive simulations and compared to that of conventional GPSR. It has been found that the use of DRESM for ad hoc networks is very promising.

From the simulation results it is obvious that the DRESM scheme can effectively capture the interaction between the several proposed metrics for the purpose of multi-objective route selection in MANETs. Simulation results show that the proposed DRESM scheme provides less delay and enhances packet delivery ratio. It is also seen from the simulation results that DRESM can find routs between communicating nodes whose cost is close to the optimum.

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