Paper

Link Quality and Energy Aware Geographical Routing in MANETs using Fuzzy Logics

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Abstract—In literature, varieties of topology and geographical routing protocols have been proposed for routing in the MANETs. It is widely accepted that the geographical routings are a superior decision than topological routings. Majority of geographical routing protocols assume an ideal network model and choose the route that contains minimum number of hops. However, in reality, nodes have limited battery power and wireless links are additionally unreliable, so they may highly affect the routing procedure. Thus, for reliable data transmission, condition of the network such as link quality and residual energy must be considered. This paper aims to propose a novel multi-metric geographical routing protocol that considers both links-quality and energy metric along with progress metric to choose the next optimal node. The progress is determined by utilizing greedy as well as compass routing rather than pure greedy routing schemes. To combine these metrics, fuzzy logics are used to get the optimal result. Further, the protocol deals with "hole" problem and proposes a technique to overcome it. Simulations show that the proposed scheme performs better in terms of the packet delivery ratio, throughput and residual energy than other existing protocols.

Keywords—*GPSR, LAR, MANET, RSSI, SINR, SNR.*

1. Introduction

A mobile ad hoc network (MANET) is a self-organizing infrastructure-less network that communicates over wireless links through mobile nodes. These nodes are free to move randomly and form a temporary network without the help of centralized administration. Hence, these nodes play a major role in the routing process, being as host as well as router at the same time. These nodes can communicate directly to other node if they reside within the transmission range of each other. However, if nodes reside beyond the transmission range, then they have to be dependent on each another to forward messages from source to the destination. Therefore, in such multi-hop scenarios, routing protocols are needed to route data.

A variety of routing protocols have been proposed to route data in MANETs. These routing protocols are often classified as topology based and position based routing protocols. The topology based routing protocols do flooding of messages, maintain a routing table to record routes between nodes, and find a path from source to destination. The topology based routing protocols are reactive or proactive in nature. The proactive routing protocols maintain complete routing information about the network. On the other hand, reactive routing protocols start path discovery only to the destination and maintain the information about only active routes instead of maintaining the overall network information. These routing protocols broadcast route request blindly that produces the high routing overhead and chance of collisions. Another issue would be caused by breakage of the links. If the nodes are moving with high speed, it will produce frequent link changes and these changes will reduce successful delivery of packets, increasing traffic overhead, increase packet drop rates, excess energy consumption and increase end-to-end delay.

To overcome these problems geographical routing protocols are accepted potentially, scalable and efficient solution for routing in MANETs. The geographical routing utilizes location information of nodes to enhance the route discovery process by limiting the forwarding zone to decrease the number of nodes participating in routing process. Since in geographical routings, the nodes locally select next hop node based on the neighborhood information and destination location. They do require neither route establishment information nor predestination state like topological routing protocols.

The main component of geographic routing is usually a greedy forwarding mechanism, whereby each node forwards a packet to the neighbor that is closest to the destination. Each intermediate node applies this greedy principle until the destination is reached. However, original greedy forwarding mechanism does not consider any other factors that can influence routing procedure, e.g. link quality and energy level. Several recent researches have verified that traditional wireless routing protocols treat the wireless link as a wired link, and focus on finding a fixed path between a source and destination. However, links are broken often due to the mobility and depleted energy level of the nodes. In such scenarios, wireless links are highly unreliable in MANET [1], [2], this may increase retransmission as well as energy wastage. Therefore, reliable data transmission and energy efficiency are biggest challenges in MANET. The another major problem of greedy forwarding is, "hole" problem which may arise due to smaller request zone or energy exhaustion of the hole boundary nodes. The nodes

located on the boundaries of holes may suffer from excessive energy consumption of the whole boundary nodes. To overcome hole problem, various perimeter routing protocol such as GPSR [3], GOAFR [4] and GAF [5], have been proposed. According to these schemes, boundaries nodes are used for data delivery instead of general node and it results excessive energy consumption and congestion at hole boundary nodes.

Therefore, in this paper a novel geographical routing protocol that discovers an optimal route by considering the link quality and residual energy of nodes is presented. The key features of proposed protocol include:

- Selecting an optimal next forwarding node by considering the both link quality, energy metric and progress metric. To combine these metrics we use the fuzzy logic interface.

- Design an efficient hole identification and detection mechanism for effective routing in presence of the hole.

- Comparison of proposed protocol and its outcomes with other geographic routing protocols.

The remainder of this article is organized as follows. In Section 2, the existing works that deal with energy and link stability related issues in geographical routing protocols are discussed. The Section 3 describes the metrics used in this work. In Section 4 the key features of proposed work are outlined. The results of simulation that evaluates the performance of proposed protocol against other existing protocols are described in Section 5. Conclusion and future directions are presented in Section 6.

2. Related Work

2.1. Link Quality Aware Routing Protocols

In literature, a majority of researches assume that the wireless links are reliable and stable. However, links are highly unreliable and unstable. Dube *et al.* [6] proposed a novel route discovery scheme by considering both signal strength and link stability of the nodes to choose a longer-lived route. The protocol selected the node based on its average signal strength to exchange a packet. Zuniga and Krishnamachari [7] worked in the direction of variation in link quality (poor or good) against distance metric. They found that quality of links highly affects the greedy forwarding scheme. As a result, packet drops rate and energy consumptions would be increased by doing retransmissions.

In paper [8], the authors used the signal strength as a parameter to estimate the link stability of the route. In this work, the authors considered power control techniques along with the location information of the nodes to reduce a significant amount of energy consumption and communication overhead.

Chen *et al.* in [9] proposed Link Quality Estimation Based Routing (LQER) protocol that takes decisions about data forwarding on the basis of a dynamic window that stores the history of successful transmission over the link. In paper [10], the authors have presented a new link quality estimation method that effectively calculates the link quality of the nodes. To measure the link quality of the nodes, the authors categorized links as short and long-term quality links. In addition, they have also worked with variation in link quality. Tsai *et al.* [11] enhanced the route discovery process of AODV routing protocol by considering SINR and hop count metric. The protocol monitors and maintains the link quality by measuring the SINR values of all the received packets from its neighbors and selects the route, which has, SINR value above a certain predetermined threshold values to make a stable route from source to destination. Few recent works in the direction of link quality are also discussed in [1], [2], [12], [13].

2.2. Energy Aware Ad Hoc Routing Protocols

Energy-aware routing is an important issue in MANETs and in literature extensive research works had been proposed in this area. Yu *et al.* [14] proposed Geographical and Energy Aware Routing (GEAR), which uses energy metric and location information to design a selection heuristics to route a packet towards the destination. The key feature of GEAR is to restrict the number of interests in direct diffusion within a certain region rather than sending the interests to the whole network. As a result, the protocol can conserve more energy than direct diffusion method. In paper [15], the authors have introduced an energy aware routing protocol, naming, Energy Efficient Location Aided Routing (EELAR) protocol that tries to achieve significant reduction in terms of the energy consumption and routing overhead by limiting the route discovery into a small forwarding zone.

In [16] the authors proposed a loop free energy efficient routing protocol with less communication overhead, naming as Energy-efficient Beaconless Geographic Routing (EBGR). EBGR selects the next node based on the energy-optimal forwarding distance. Then, they defined the upper and lower limits for hop count as well as energy usage for a route between source and destination node. The results demonstrate that the expected total energy consumption for a route is closer to the lower bound.

GAF protocol [5] had been introduced as a solution to reduce energy consumption during routing process. The protocol tries to save energy not only at the time of transmission and reception of packets but also considers the energy consumption in idle (or listening) mode. The authors divided the whole network's region into fixed square grids by using the location information of nodes. The protocol ranked the nodes according to their residual energy level and nodes can switch between sleeping and listing mode within its own grid. Each grid has only one active sensor node based on defined ranking rules and a higher ranker node handles routing within its grid. This scheme extends the lifetime of network.

Another span energy aware routing protocol [17], had been

proposed which broadcasts a route request messages locally to discover a route instead of using location information of nodes. The protocol elects coordinators among all nodes in the network, on rotation basis. These elected coordinators performed multi-hop packet routing within the ad hoc network, while other nodes stay in power saving mode and wait for their chance to become a coordinator. To forward packets, greedy forwarding scheme is used. A similar work had been proposed to extend the lifetime of network naming as, energy-aware data-centric routing (EAD) [18] based on the concept of virtual backbones. MECN [19] is a location-based protocol, which uses mobile sensors to maintain a minimum energy network. For this purpose, it computes an optimal spanning tree with sink as a root and selects only a minimum power path from source to destination. The other energy efficient routing protocols naming, location based energy efficient reliable routing in wireless sensor network (LEAR), discussed in [20] also contributes to reduce the energy consumption and makes greedy routing energy efficient. The most recent research works in this direction is also presented in [21]–[24].

2.3. Link Quality and Energy Aware Routing Protocol

In literature, a very few protocols are proposed to deal with the link quality and energy metric together during route discovery and maintenance phases. In papers [25], [26] authors aimed to evaluate the performance of network in the presence of wireless link errors and tried to relate how link error rates affect the retransmission-metric. The protocol computes a cost function to capture the energy expended in reliable data transfer, for both reliable and unreliable link layers.

In paper [27], another work had been done in the direction of finding an energy efficient reliable path in presence of unreliable links. The protocol integrates the power control techniques with the energy metric to find a stable energy efficient path between source and the destination.

Range *et al*. [28] proposed a routing protocol, which considers link stability and residual energy of mobile nodes while selecting a next forwarding node. Multi-objective linear programming methods are used to formulate the mathematical model to balance the opposite effects of energy aware and link stable routing protocols. By doing this, the protocol tries to find a more stable and shorter path between source and destination.

In paper [29], the authors proposed a routing protocol by combining link stability and energy drain rate metric into the route discovery procedure naming as, link stability and energy aware routing protocol (LAER). The protocol tries to reduce the traffic load on the nodes as well as significant reduction in control overhead. However, LAER does not able to discriminate between links of the same age.

In paper [30], authors designed an energy efficient and link stable routing scheme for the route discovery and the route maintenance phases. The protocol computed the link stability by measuring the received signal strength (RSS) of

consecutive packets. Further, these link stability scores are added to compute the route stability of the constructed route.

Vazifehdan *et al*. [31], focused on the major issues, i.e. energy, reliability and prolonging the lifetime of the network and proposed two energy efficient routing methods for wireless ad hoc networks. The first one is called as Reliable Minimum Energy Cost Routing (RMECR) that considers the energy metric as well as link quality to find energy-efficient and reliable paths to increase the network lifetime. On the other hand, the second one considers only energy metric to minimize the total energy required for end-to-end packet traversal and named as Reliable Minimum Energy Routing (RMER).

2.4. Hole Detection based Routing Protocol

Generally, geographical routing protocols use Greedy forwarding [32] scheme to route data. This scheme tries to find the most suitable neighbor node to minimize the distance to the destination in each step to bring the message closer to the destination. However, this scheme fails in the presence of hole. The face routing, or perimeter routings have been proposed as a solution to overcome the hole situations. Karp *et al*. [3] designed a perimeter routing as the solution of this problem to improve the greedy forwarding protocol. This scheme is known as GPSR (Greedy Perimeter Stateless Routing). GOAFR [4] is another method, admired to deal with the hole problem in greedy routing. This scheme combined the greed forwarding with Adaptive Face Routing (AFR) to identify and recover the holes.

In [33], the authors defined hole as simple region enclosed by a polygonal circle, containing all the nodes where local minima can appear. The authors categorized the stuck node as weak and strong stuck node. The protocol bypasses these stuck nodes and tried to find the route outside the local minima for successful transmission. Several other researchers also discussed the hole with their solutions in [34]–[36].

3. Metrics Overview

In this section, we provide the definition of each metric for the better understanding of our proposed work. The notations used to define metrics are listed in Table 1 with their descriptions.

3.1. Energy Metric

Due to limited battery power of nodes, energy is the most important issue in the MANETs. The energy level of the nodes can deplete quickly if they involve in multi-hop communication. For reliable and successful communication, the protocol should consider energy states of the nodes during route finding. Therefore, proposed protocol keeps track of the energy state of the nodes based on the concept

Table 1
Used notations

Notation	Description
$E_{fw(m,d)}$	Energy used in transmitting and receiving m packets
$E_{Tx(m,d)}$	Transmitter energy consumption
$E_{Rx(m)}$	Receiver energy consumption
M	Number of packets
$E_{elec.}$	Electronics energy consumption per bit in the transmitter and receiver mobile nodes
ε_{fs}	Amplifier energy consumption in transmitter nodes in free space
ε_{mp}	Amplifier energy consumption in transmitter nodes in multipath
E_{resi}	Residual energy of node
E_{inital}	Initial energy of mobile nodes
D	Euclidian distance between transmitter and receiver
Pt	Transmission power of transmitter
Pr	Power received at the receiver
Gt	Gain of transmitter antenna
Gr	Gain of receiver antenna
Λ	Wave length of RF signal
$Pref$	Reference power
N	Signal propagation constant
C	Received signal strength at a distance of one meter

of residual energy of the node. For better utilization of energy, authors need energy models to prevent more energy consumption in MANETs.

In this work, the first order radio model to compute the energy consumption during transmitting and receiving of packets is used. The first order model is the basic model in the area of routing protocol evaluation in MANETs. According to this model, the energy consumed for transmitting and receiving m bit data over distance d is calculated by formula given in Eq. (1). In Eq. (2) the energy required to transmit a packet m over distance d is to be dependent on the distance between the nodes and calculated by Eq. (2). In Eq. (3) energy to receive, this message is calculated and the residual energy of the node is given in Eq. (4). The notation employed in energy models are given with their meanings in Table 1.

$$E_{fw(m,d)} = E_{Tx(m,d)} + E_{Rx(m)}, \tag{1}$$

$$E_{Tx(m,d)} = \begin{cases} mE_{elec.} + m\varepsilon_{fs}d^2 & \text{if } d < d0 \\ mE_{elec.} + m\varepsilon_{mp}d^4 & \text{if } d \geq d0 \end{cases}, \tag{2}$$

$$E_{Rx(m)} = mE_{elec.}, \tag{3}$$

$$E_{resi} = E + E_{inital} - E_{fw}. \tag{4}$$

3.2. Link Quality Metric

The geographical routing protocols choose routes based on shortest path criterion. The greedy forwarding is the best

example of this criterion and selects farthest neighbor node as a next forwarding node without thinking about the link quality of the nodes. A small movement in selected node may lead link breakage and cause unstable routes. These unstable routes can increase packet loss and control overhead. Thus, the shortest path is not always the best one, other metrics should also be considered while selecting next neighbor node in a range.

In literature, majority of works evaluate the link quality Received Signal Strength Indicator either (RSSI) or Packet Reception Rate (PRR) parameters. These schemes perform well on a sparse network, where the chance of interference among nodes is low. However, as the network density increases, interference among the nodes will also increase. Under such situations, RSSI or PRR does not give a good indication of link quality. For example, if the interference does not exist among nodes, higher RSSI reading generally translates into a higher PRR. As interference increases, a higher RSSI may not result in a higher PRR.

The researches reveal that a node may not always be able to accurately differentiate between packet loss due to a weak signal quality and due to interference among the nodes. Thus, the paper aims to evaluate the link quality more accurately by considering all the factors like signal strength, noise and interference. In theory, the relation between RSSI and interference is calculated and known as a Signal to Interference Plus Noise Ratio (SINR). To understand the SINR, there is need to understand the concept of RSSI first. RSSI provides a measure of the signal strength at the receiver end and it can be correlated to the distance between two nodes. According to Frii's free space transmission equation, the received signal strength decreases as distance increases. The relation between RSSI and distance is given in Eq. (5):

$$\text{RSSI} = -10 \cdot n \log d + C. \tag{5}$$

The idea behind RSSI is that the configured transmission power at the transmitting device Pt directly affects the receiving power at the receiving device Pr According to Friis' free space transmission equation, the detected signal strength decreases quadratically with the distance to the sender is shown in Eq. (6).

$$Pr = Pt \cdot Gt \cdot Gr \cdot \frac{\lambda^2}{4\pi d^2}. \tag{6}$$

The Received Signal Strength (RSS) is usually converted into RSSI that is defined as a ratio of the received power to the reference power $Pref$. Typically, the reference power represents an absolute value of $Pref = 1$ mW, RSSI, and SINR values are calculated in Eqs. (7) and (8) respectively.

$$\text{RSSI} = 10 \log \frac{Pr(Signal)}{Pref}. \tag{7}$$

$$\text{SNIR} = \frac{\text{RSSI}}{Noise + Interference}. \tag{8}$$

3.3. Progress

The pure geographical routing protocols choose the next-forwarding node either as distance-based strategy (MFR) [32] to reduce the hop count, or as direction-based strategy (Compass) [37] to minimize the spatial distance. The distance based routing schemes help to reduce the end-to-end delay, however badly affect the energy usage of the nodes. On contrast, the direction based routings increase the stability and consumes less energy but increases overall end to end delay. To overcome these issues of distance and direction based routing protocols, our study considers both the strategies and propose a hybrid progress scheme to find an optimal forwarding node in a range. Distance and direction are represented as Dis_Progress and Dir_Progress respectively. The calculations of these metrics are shown in Eqs. (9) and (10) respectively:

$$\text{Dis\_Progress} = \frac{R - d}{R}, \qquad (9)$$

$$\text{Dir\_Progress} = \frac{\theta - \alpha}{\theta}, \qquad (10)$$

where R is transmission range, d is the distance between two nodes, θ is angle formed by the request zone with line of sight and α is the angle formed by node inside the request zone.

4. Proposed Protocol

Most of the geographical routing protocols elect the routes based on greedy scheme without considering the condition of the network such as link quality and residual energy of the nodes, which incur the unstable and unreliable route. In addition, once a link failure occurs, a re-route discovery mechanism is initiated that produce high routing overheads. Thus, in this study, authors try to propose a protocol to improve the routing process by combining multiple metrics, e.g. energy level, SINR and progress rather than single metric.

4.1. Network Model and Assumptions

The mobile ad hoc network (MANET) which includes mobile nodes that are randomly deployed in a two dimensional area and each node has its own distinctive position. Every node knows its own location info through Global Position System (GPS), and might acquire different nodes location via a location service protocol. The source is aware of its own location as well as location information of destination. Here, it is assumed that the nodes are same and having a same transmission range R. The communication links between the nodes are bidirectional. The nodes are assumed to be connected only when the distance between them is less than transmission range. The nodes have equal initial energy level and they have the capability of forwarding an incoming packet to one among its neighboring nodes as well as receive information from a transmitting node.

4.2. Protocol Overview

When source S wants to send data to destination D, S utilizes the known location information about destination D to define the expected zone around the destination. Then it defines request zone that includes both the source and complete expected zone. The concept of expected and request zone is originally proposed by the authors of LAR [38]. They proposed a small rectangle shaped request zone. The request zone includes the source and circular region around destination. In this work, the triangular shape request zone is used instead of the rectangular size request zone to forward the route request. The triangular shape request zone contains less number of nodes than rectangular shaped request zone due to its smaller area. It helps to minimize the probability of collisions and reduces the significant amount in routing overheads.

Once a sources defines request zone, it sends route request to other nodes. When a node receives the request, it uses the location information for determining if it resides in a request zone or not. There are many methods in mathematics to find a node in triangular zone. For example, in Fig. 1, the node determines its angle and distance by using the Eqs. (1) and (2). If its angle is smaller than angle θ and distance is less than $d + r$, than nodes Y, V, X and U will reside within the triangular request zone and they can take part in routing process. However, the nodes W, N and Z discard the request, as they are not inside the request zone.
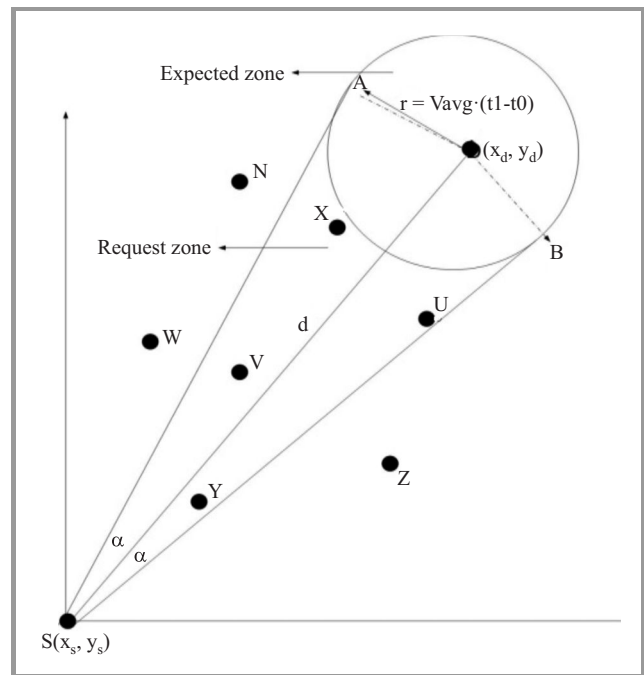

Fig. 1. Request zone formation.

4.3. Forwarding Strategy

The geographical routing protocol uses greedy forwarding scheme, which assumes an ideal network model and completes data transmission without considering other major factors like energy consumption and link quality. These

factors may highly influence the routing procedure. Hence, these factors should also be considered while routing data from source and destination. Therefore, in this section a fuzzy based multi-metric scheme is proposed to select an optimal next forwarding node, which increases the quality of route in terms of both stability and reliability over conventional geographical routing schemes. The protocol combines link quality and energy metric to select the optimal next neighbor node. Generally, the multi-metric routing protocols use the weight factors to combine multiple metrics to get the final score over an available path. Although a weight factor is easy and popular way to combine multiple metrics, for best score, there are no predefined rules to determine the weight factors between metrics. The fixed weights cannot satisfy all the network scenarios. Therefore, to overcome these limitations of the weight selection problem, the fuzzy logics is taken as a solution. To select the next forwarding node, all the metrics are taken as an input for the fuzzy logic engine. Then, fuzzy rules are applied on these inputs and results show the probability of next forwarding node.

Fuzzy logics are a computational framework based on the concepts of the theory of fuzzy sets, fuzzy rules, and fuzzy inference. In traditional logic, an object takes on a value of either zero or one. In fuzzy logic, a statement can assume any real value between 0 and 1 representing the degree to which an element belongs to a given set. Fuzzy system has three main components: a fuzzification block, fuzzy rule base for inferencing (decision-making unit), and a defuzzification interface. The fuzzification (input) maps the (crisp) input values into fuzzy values, by computing their membership in all linguistic terms defined in the corresponding input domain. The inference engine maps inputs by combining a set of membership functions with the fuzzy rules to get fuzzy outputs. The defuzzification interface computes the (crisp) output values by combining the output of the rules and performing a specific transformation. Centroid of the area (COA), mean of maximum (MOM) and fuzzy mean (FM) are a wide variety of methods for defuzzifying the fuzzy output.

Table 2 shows, each input is being presented by three linguistic values: weak, medium, and high, for link quality. The values good, average and low are taken for residual energy parameter. The use of very far, far and close for distance and the values for deviation are set as less, mid and more directed. The values of very high, high, good, average, low and very low are used for output parameters. The

Table 2
Linguistic values for inputs

Input parameter	Values		
Residual energy	High	Average	Low
Link quality	Good	Medium	Weak
Dis_Progress	Close	Far	Very far
Dir_Progress	More deviated	Mid deviated	Less deviated

triangular membership function is used for fuzzification of given input since it produces low computation overheads. Mamdani fuzzy interface system is used as fuzzy inference system to evaluate the rules. These fuzzy rules consist if and then parts which are used to formulate the conditional statements that comprise fuzzy logic.

In general, one rule alone is not effective to produce the solution. Two or more rules that can play off one another are needed to merge for output. The proposed protocol takes 4 input variables which are converted into linguistic values by using the membership functions to determine the membership degree of nodes.

The outcomes of fuzzification process are passed to the inference engine for further processing. Inferencing process applies fuzzy rules on these fuzzified values and in this work, there are 3^4 i.e. 81 different fuzzy rules. The Table 3 shows a few samples of rules used in presented research work. The output of each rule is a fuzzy set and the output (optimum cost) value lies between 0 and 1. Finally, the resulting output set is defuzzified by using a COA method in a single output.

Table 3
Few fuzzy rules used for inferencing

Link quality	Residual energy	Dir_Progress	Dis_Progress	Optimal function
Good	High	More_Directed	Close	Very high
Good	Hihg	More_Directed	Far	High
Good	High	Mid_Directed	Far	Average
Medium	High	More_Directed	Close	Good
Medium	Average	Mid_Directed	Close	Average
Good	Low	More_Directed	Far	Low
Weak	Average	More_Directed	Close	Low
Weak	Low	Less_Directed	Far	Very low

In Fig. 2, source node S has 13 neighbors within its transmission range. As was discussed earlier, nodes, which lie
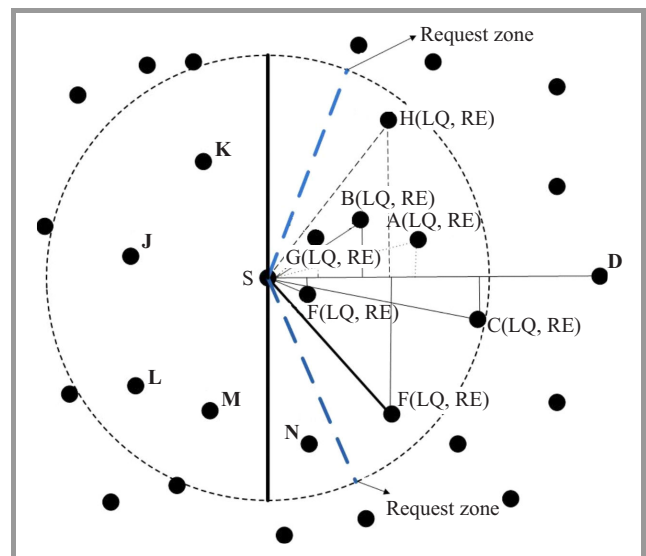

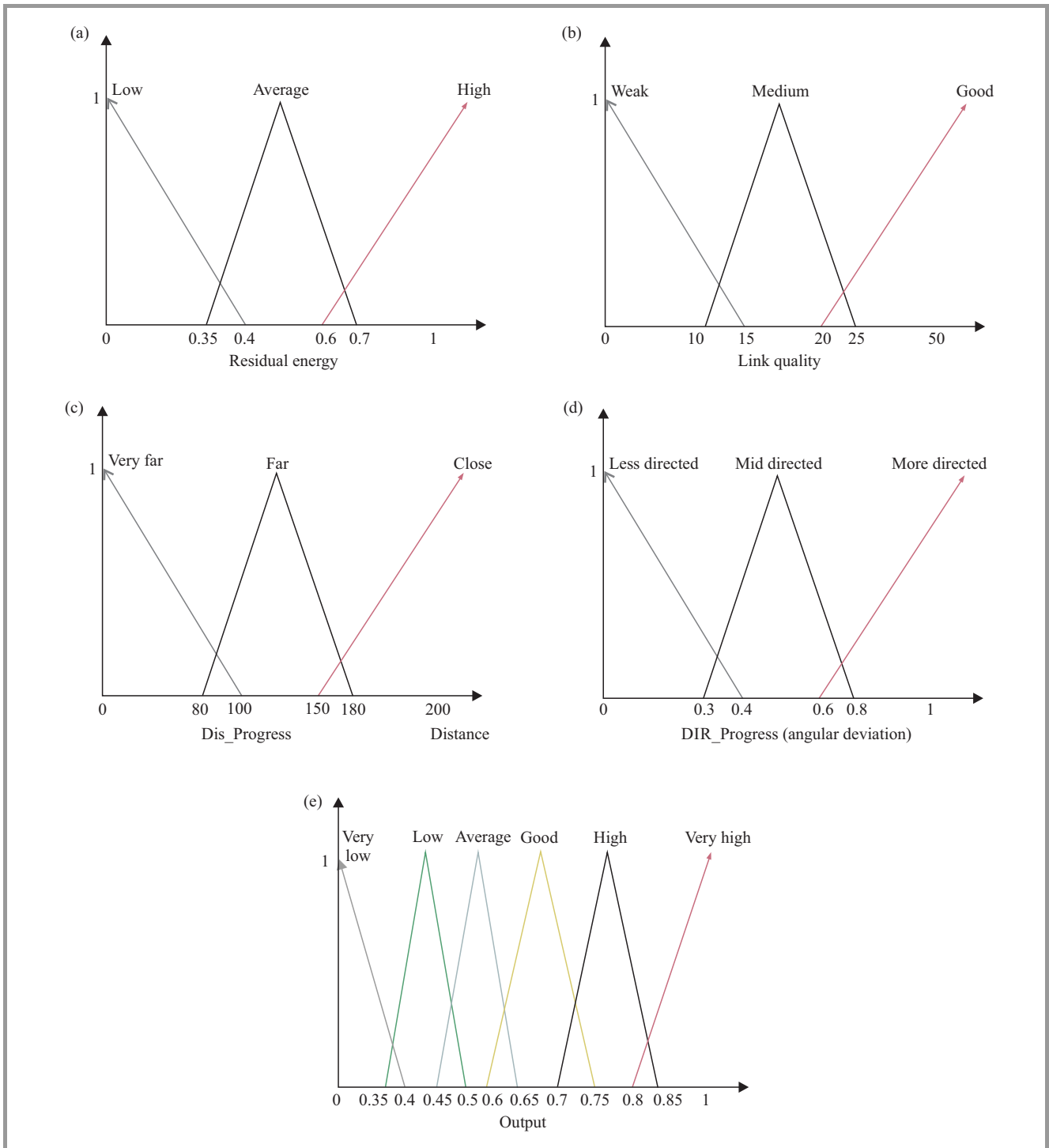**Fig. 2.** Selection of optimal node.

Fig. 3. (a) membership function for residual energy, (b) membership function for link quality, (c) membership function for input distance, (d) membership function for input direction, (e) output of given inputs.

inside the request zone may only be the next forwarding node. Thus, only those neighbors are evaluated, which are in the request zone towards the destination D. The protocol compares the residual energy, link-quality, distances and deviations (direction) of the nodes A–H.

Suppose the residual energy, link quality (SINR), distances and angular deviations of nodes are $(E_A, LQ_A, d_A, \alpha_A)$, $(E_B, LQ_B, d_B, \alpha_B)$, $(E_C, LQ_C, d_C, \alpha_C)$, $(E_E, LQ_E, d_E, \alpha_E)$, $(E_F,$

$LQ_F, d_F, \alpha_F)$, $(E_G, LQ_G, d_G, \alpha_G)$ and $(E_H, LQ_H, d_H, \alpha_H)$ respectively. The residual energy(RE), link quality(LQ), Dis_Progress (d) and Dir_Progress (α) of nodes are given as $(E_A > E_B > E_G > E_H > E_F > E_C)$, $(LQ_G > LQ_A > LQ_E > LQ_B > LQ_F > LQ_H > LQ_C)$, $(d_C > d_A > d_H > d_F > d_B > d_G > d_E)$ and $(\alpha_A < \alpha_C < \alpha_B < \alpha_B < \alpha_G < \alpha_F < \alpha_H)$.

Based on the information node A is selected as the next forwarding node since, it has high link quality, good residual

energy level, less deviated from LOS and closer to destination.

For an example, if there is a fuzzy rule like, "if SINR (link quality) is high, residual energy is good, Dis_progress (distance) is close and Dir_Progress (deviation) is very high then the fuzzy cost is very high". Suppose a node having a link quality 30 dBm, residual energy is 0.8 J, distance is 180.56 m and value of the deviation is 0.864 then the output value is 0.886. This output value indicates the fuzzy cost for specified node and it is high for the above-mentioned rule. The fuzzy system gives output, compromised all the routing metrics and selects the node, which is optimal in all the terms.

Figures 3a-d respectively, show the membership functions of the residual energy, link quality, distance, and direction (angular deviation) amount.

Figure 3e depicts the membership function of the output unit before the defuzzification of results. The input parameters are taken by a membership function with degree one and it becomes a fuzzy value.

In the example discussed in Fig. 2, nodes A–H may be the next forwarding node, thus for these nodes, all metrics are considered as input parameters and the result table shows outcomes for optimally selected node in Table 4. The result shows that the value of fuzzy cost increases on increasing the values of all metrics. In Fig. 2 node A scores the greatest fuzzy cost among all the nodes so node A will be selected as next forwarding nodes in a range.

Table 4
Result table

Node	Input (link quality, residual energy, distance, direction)	Output (node selected)
A	[30, 0.8, 180.56, 0.864]	0.886
B	[20, 0.76, 155.65, 0.634]	0.586
C	[11, 0.4, 195, 0.732, 0.703]	0.347
E	[22, 0.723, 120.43, 0.845]	0.625
F	[18, 0.632, 160.43, 0.543]	0.619
G	[32, 0.743, 130.32, 0.432]	0.645
H	[17, 0.702, 170.43, 0.345]	0.483

4.4. Hole Detection Scheme

The smaller request zone is the better choice to reduce routing overhead. However, the too small size request zone can be a reason for no or unstable routing in the request zone, still there exist a stable path outside the request zone. This situation is known as hole in the request zone. Besides the smaller request zone, there may be various other reasons for hole problem like border node selection, energy depletion etc. Therefore, in this section, a scheme to overcome the hole problem is proposed by announcing the hole's information and suggest a local healing solution for successful routing.

In example shown in Fig. 4, to forward the messages, source S first checks its neighbor table to find an optimal next forwarding neighbor within the request zone towards the desti-

nation. To find the optimal node source applies the forwarding mechanism discussed in Subsection 4.4. If source S, does not get any node in its transmission range, routing protocol gets in a hole and node S is called a stuck node. In this situation, most of the geographical routing protocols depend on perimeter routing [3] to find a detour path, that makes routing inefficient.
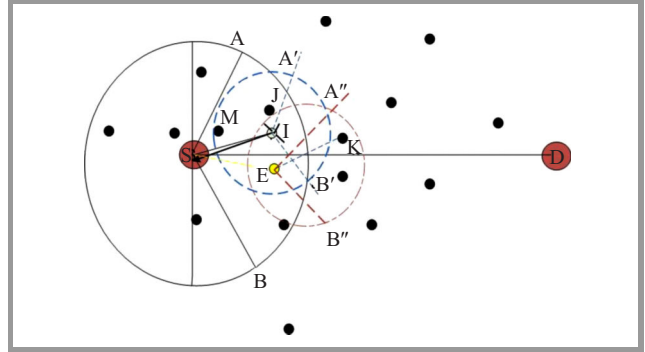

Fig. 4. Hole detection scheme. (See color pictures online at www.nit.eu/publications/journal-jtit)

Hence, to overcome the hole problem, this protocol, first, suggest a mechanism for immediate detection of holes. After that, the information about the hole is announced among the nearby nodes (about the request zone angle θ and hole size).

In Fig. 4, source S chooses node I as a next forwarding node. Node I defines its own triangular shaped request zone (IA'B') and starts finding a node in its transmission range within defined request zone. Unfortunately, the node I does not find any node to forward a packet to a given destination.

Thus, node I will consider itself as a stuck (blocked) in this direction and I will advertise this hole information to its neighbors. As neighbors get the information, they mark node I as stuck node and they will not choose node I for further communications.

Based on this information, S marks I as stuck node and tries to find another optimal neighbor in its range to forward the messages. After marking I as stuck node E is selected as a next forwarding node. The request zone formed by source S is ASB given by black lines. The transmission range of node I is given by blue dotted circle and request zone A'IB' by blue dotted lines. The request zone A'IB' does not contain any node to forward the message. Red color dotted lines show the transmission range and request zone of node E is EA "B". Then node E selects the K as a next forwarding node to route data to destination D.

5. Performance Evaluation

In this section, to evaluate the performance of the proposed protocol, implementation is carried out in Matlab 7.0 and simulation results are compared with greedy perimeter stateless routing (GPSR) and Location-Aided Routing scheme (LAR).

The nodes vary from 50 to 250 and uniformly deployed in 1000 m^2 area. The nodes have speeds between 0 to 25 m/s with 30 s as pause time. Each node has equal transmission range and equal initial energy levels. The transmission range is set 200 m and node's initial energy is taken as 1 J. For simulation work, the channel capacity of mobile nodes is 2 Mb/s and Random Waypoint Mobility Model is implemented as the mobility model. The antenna heights and gains of all nodes are taken at 1 m and 1 m respectively. Two Ray path loss model is used as the radio propagation model. The simulation runs for 300 s. The IEEE 802.11b is used to simulate the MAC layer, which contains all the mechanisms, which use the CSMA/CA technique based on the Distributed Coordination Function (DCF) access method (Table 5). Authors correlate the link quality with SINR and in this work, the SINR is calculated in terms of SNR. To calculate the SNR values, the nodes in Additive White Gaussian Noise (AWGN) environment is deployed along with external RF interference noise sources.

Table 5
Simulation parameters

Name	Value
Topology size	1000×1000 m
Number of nodes	50–250
Speed	5–25 m/s
Mobility model	Random way point
Simulation time	300 s
Channel rate	2 Mb/s
Channel type	Wireless channels
Mobility model	Random way point
MAC Layer protocol	IEEE 802.11b
Radio propagation model	Two ray ground
Transmission range	200 m
Traffic type	CBR
CBR Packet size	100 bytes

5.1. Performance Metrics

Packet delivery ratio. This metric is defined as the number of delivered data packets to destination and calculated as the ratio of number of received data packets to the number of sent data packets. This metric represent the reliability of the protocol in terms of data delivery.

Average energy consumption. This metric indicates energy consumed in the nodes of the network. This metric is important for prolonging the network lifetime.

Average end-to-end delay. This metric indicates latency in the communication network. It is calculated as the ratio of the total time taken by all the packets to reach the destination of the total number of packets. The protocol should have minimum average delay for prompt data transfer.

Throughput. It is defined as rate of successful message delivery over a communication channel and generally, it is measured in bits per second.

5.2. Simulation Impact of Node Density

In this section, the influence of node density on the above discussed metrics and analyzed the behavior of protocols in dense and sparse network are discussed. In simulation, the nodes are varying from 50, 100, 150, 200 and 250. The speed is kept on 10 m/s. Four traffic connections are used from source to destination including CBR traffic pattern. The proposed protocol combines link quality (SINR), progress (distance, direction) and residual energy when selecting a next forwarding node. This can avoid the occurrence of the worst situations, such as choosing the most distant neighbor that may has a poor link quality.

First, the packet delivery ratio of proposed and existing protocols (GPSR, LAR) is compared with the varying number of nodes. The results are shown in Fig. 5a. The packet delivery ratio of the proposed protocol is comparatively high in comparison with LAR and GPSR since, proposed scheme selects the next hop by combining the link quality and residual energy with distance metric. By using these important metrics, the proposed protocol improves the packet delivery ratio in comparison with existing single metric protocols.

In presence of hole, the LAR does retransmission and GPSR switches to perimeter mode to route data. As a consequences delay increases during the packet transmission, which causes lower packet delivery ratio. In this situation, our protocol performs better than others do. Our scheme reduces the retransmissions counts by healing the hole by applying the scheme proposed in Subsection 4.4. The results also show that packet delivery ratio of the all protocols drop as number of nodes increases. Figure 5b presents energy consumption vs. varying nodes for GPSR, LAR and our proposed protocol. The result shows that the proposed solution performs better in terms of energy consumption than GPSR and LAR routing protocols and the network lifetime is improved significantly. Figure 5c shows that the average delay of the proposed work is higher than the LAR and GPSR protocol. The proposed protocol focuses on residual energy, link quality and distance to select next forwarding node instead of shortest path. It produces computation overheads and enhances the end-to-end delay. Figure 5d, illustrates that the proposed protocol improves the network throughput in comparison with GPSR and LAR protocols. On average, it achieves better throughput than GPSR and LAR because it considers link quality metric when choosing the next node. By using this metric, the protocol saves bandwidth and this saved bandwidth can be utilized to transmit other packets. As a result, it improves network throughput. The reason behind the better throughput of presented protocol is that it reduces the retransmission counts. On the other hand, in GPSR retransmission is taken place when node dies and, in LAR when greedy forwarding fails. In these bad situations, retransmission
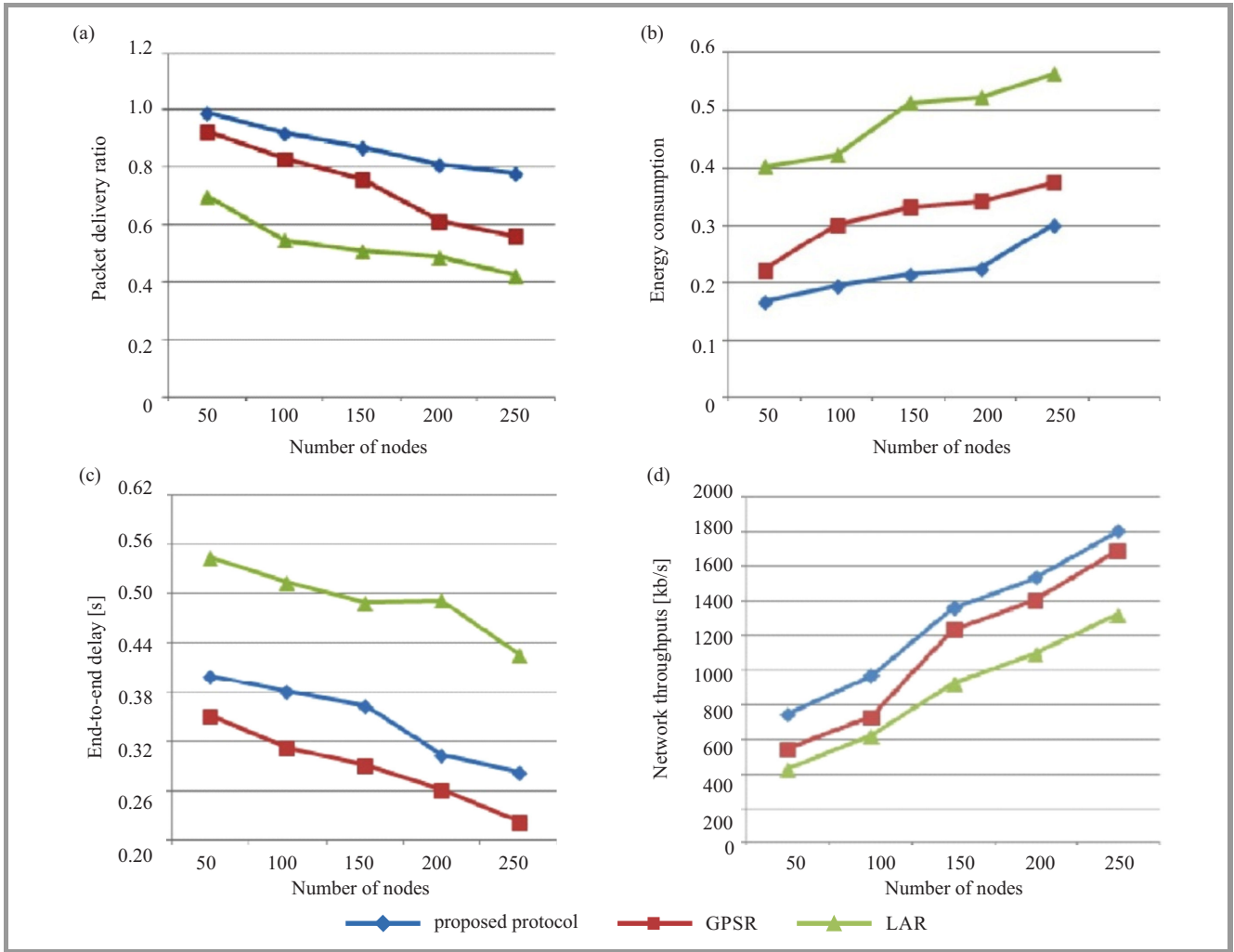
Fig. 5. (a) packet delivery ratio, (b) energy consumption, (c) end-to-end delay, and (d) network throughput at 10 m/s.

will take place heavily and consume excessive amount of spectrum. As a result, in GPSR and LAR the network throughput is low. The results also show that on increasing the nodes the value of throughput goes down for all the nodes.

To study the impact of speed, the node speed is varied from 5 to 25 m/s while the number of nodes are fixed at 50. The other parameters and settings are kept same. The higher speed will cause the large number of link failures as well as a large number of collisions due to frequent movements of nodes. Therefore, an increase in speed definitely affects the performance of routing protocols.

The results show that the packet delivery ratio of the proposed protocol is better than other routing protocols since, it considers the good link quality nodes to route data (Fig. 6a). On the other hand, LAR and GPSR select the node, closer to the destination that may have a bad link quality. The packet delivery ratio of all the protocols rises in starting and then goes down with the increase in node's speed. The reason behind is that if the node's speed increases, the connectivity between nodes causes a lower packet delivery ratio.

The result reveals that energy consumption throughput of all the routing protocols that decreases with an increase in velocity of a node (Fig. 6b) in Fig. 6c, the plot for the end-to-end delay vs. varying speeds is given that shows the end-to-end delay of all the protocols go down with the increasing velocity of nodes. The reason behind this huge fall is that the time to carry and forward a packet decreases with the increase in speed. As speed increases, the throughput goes down for all the protocols (Fig. 6d).

6. Conclusions

Due to the dynamic nature and limited battery power of mobile nodes, link quality and energy metrics play an important role for successful and reliable communication in MANETs. Hence, these parameters should be considered while designing an efficient and optimal routing protocol. In this paper, a novel multi-metric optimal routing protocol for reliable and stable communication in MANET was presented. It combines link quality information and residual energy with progress metric to select the next forwarding node. Fuzzy logics are used to combine these
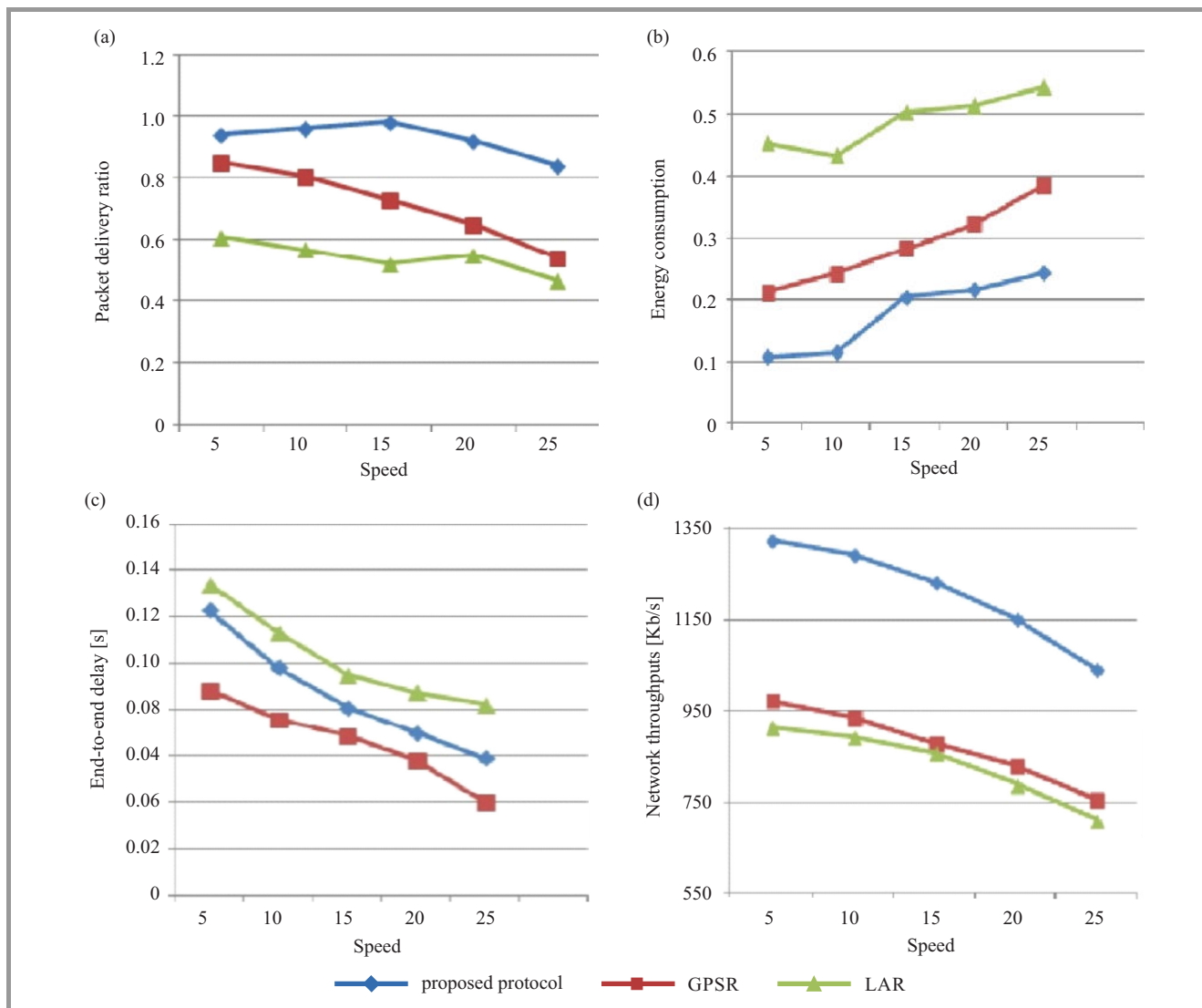
Fig. 6. (a) packet delivery ratio, (b) energy consumption, (c) end-to-end delay, (d) throughput.

metrics, which help to o find the optimal output in terms of optimal forwarding nodes. Further, the protocol aims to deal with the hole problem and proposes a method to overcome it. Matlab software is used to simulate the proposed work. The results are compared with GPSR and LAR for all the metrics at varying node density and varying speeds. The results reveal that the proposed protocol is more energy efficient and reliable than GPSR and LAR routing protocols. It improves the packet delivery rate, throughput and reliability of the transmission of data with a small delay.

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