An Improvement of OLSR Using Fuzzy Logic Based MPR selection

Narangerel Dashbyamba, Celimuge Wu, Satoshi Ohzahata, and Toshihiko Kato
Graduate School of Information Systems, University of Electro-Communications
Chofu-shi, Tokyo, Japan
Email: {naransan}@net.is.uec.ac.jp, {clmg,ohzahata,kato}@is.uec.ac.jp

***Abstract*—Optimized Link State Routing Protocol (OLSR) is a well-known proactive routing protocol for mobile ad hoc networks. OLSR reduces the number of control messages by using MPRs to forward topology control messages as compared with typical proactive protocols. Since OLSR does not consider the node mobility and signal strength condition for the MPR (MultiPoint Relays) selection, OLSR cannot work well in a highly mobile and lossy network. In this paper, we propose a protocol which improves OLSR by taking into account the node mobility and signal strength in the selection of MPRs. We use network simulations to evaluate the proposed protocol's performance.**

I. INTRODUCTION

Optimized Link State Routing Protocol (OLSR) [1] is a well-known proactive routing protocol for ad hoc networks. OLSR provides a low control message overhead by choosing multi-point relay (MPR) nodes from the neighborhood to forward control messages. MPR nodes are chosen based on the knowledge about neighbors in two-hop communication range without considering stability of wireless signal and movements of neighbor nodes. As a result, the largest distance node is always selected as a relay node. Due to the long distance MPR selection, the packet delivery ratio remarkably degrades in a highly mobile and lossy network. Without considering the node mobility and signal strength in the MPR selection, OLSR fails to select a reliable route.

Kots and Kumar [2] have proposed a fuzzy logic based novel routing metric for MPR selection based on the energy, stability and buffer occupancy of the nodes. However, the node mobility and received signal strength are not seriously considered. McAuley et al. [3] have proposed a routing approach which calculates route cost based on the current link state database and the history of link state values. Rango et al. [4] have proposed a protocol to improve OLSR's energy performance. Sharma et al. [5] have discussed the node movement effect on the performance of OLSR, and proposed an approach which utilizes position information to deal with the mobility issue. Toutouh et al. [6] have discussed the parameter tuning of OLSR using metaheuristic algorithms. However, since the signal strength is not considered, these works [2]–[6] cannot work well in a fading environment.

In OLSR, since the MPR nodes are used to disseminate topology information and update route to the MPR selectors, the performance of OLSR can be improved by selecting proper MPR nodes. In this paper, we propose a protocol which specifies MPR nodes based on a joint fuzzy evaluation of multiple metrics including inter-node distance, signal strength and node velocity. The proposed protocol also deals with the problem of choosing the best route when there are possible multiple paths to a particular destination node. We evaluate the proposed protocol in mobile and lossy networks using computer simulations.

The remainder of the paper is organized as follows. In section II, we give a brief description of optimized link state routing protocol. In section III, we give a detailed description of the proposed protocol. Next, we present simulation results in section IV. Finally, we present our conclusions and proposals for future work in Section V.

II. OPTIMIZED LINK STATE ROUTING PROTOCOL (OLSR)

OLSR [1] is a proactive link state routing algorithm based on periodically exchanging control messages to maintain topology information about network. The novelty of OLSR is in that it minimizes the size of control messages flooded during the route update process by employing multipoint relaying strategy. Each node in the network selects a set of 1-hop neighbor nodes as MPRs (MultiPoint Relays). A node which is not in MPR set can read and process control packets but does not retransmit them. All MPRs together provide connections that cover all its up-to 2-hop neighbor nodes (see Fig. 1). When a 1-hop neighbor connects to any of 2-hop neighbors, it is called that the 1-hop neighbor is covering those 2-hop neighbors. For selecting the MPRs, each node periodically broadcasts a list of its 1-hop neighbor addresses using HELLO messages.

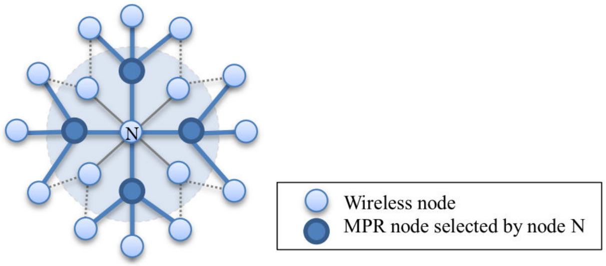

Fig. 1. Multipoint relay node selection.

In order to build intra-forwarding database for routing packets, each node periodically broadcasts specific control messages called Topology Control (TC) messages. TC messages are retransmitted by other MPRs in broadcasting mode. A periodic TC message contains the list of neighbors who have selected the TC message originator node as a MPR. By exchanging the periodic TC messages, all MPR-selector set addresses and corresponding MPR node addresses in the network are declared into entire network. Each node maintains all nodes' MPR-selector set addresses from received TC messages to construct a Topology Table. The Topology Table implies that the potential destination nodes can be reached through the corresponding last-hop node. A node may not generate any TC message when no one has selected it as MPR. Each node uses the information of neighbor tables and Topology Table for the update of routing table. Each route entry in the routing table consists of the destination address, next-hop address and estimated distance to destination.

III. PROPOSED PROTOCOL

A. Assumptions

We assume every node is able to acquire its position information by using GPS-like services. Nodes share additional information by exchanging HELLO messages. In this way, every node becomes able to know the information about its 1-hop neighbors (such as distance, received signal strength and moving speed).

B. Protocol overview

Upon reception of a HELLO message, each node evaluates the neighbor (hello sender node) by taking account of the inter-node distance, relative mobility and received signal strength. This evaluation is conducted by using a fuzzy logic algorithm and the evaluation results are used for the selection of MPR nodes. By selecting better MPRs, the proposed protocol can choose a more reliable and efficient route than OLSR. The proposed protocol may use a longer route (as compared with OLSR) for data transmissions depending on the link status.

C. Main factors considered for the MPR selection

The following three factors are calculated upon reception of a HELLO message and used to evaluate reliability of each 1-hop neighbor as being a MPR.

1) Distance Factor (DF): Distance factor indicates the distance level of a 1-hop neighbor. As shown in Eq.(1), R indicates the transmission range and $d(X)$ denotes the distance to the neighbor node X (R was 400 meters for the simulations presented in this paper).

$$DF(X) = \begin{cases} \frac{d(X)}{\mathrm{R}}, & d(X) <= \mathrm{R} \\ 1, & d(X) > \mathrm{R}. \end{cases} \tag{1}$$

2) Mobility Factor (MF): Mobility factor indicates the mobility level of 1-hop neighbors. It is calculated by Eq.(2). In here, $d_i(X)$ denotes the distance between the current node and 1-hop neighbor X at time i. α is a smoothing factor (α= 0.7). A higher value of MF indicates the more stable status of 1-hop neighbor X. MF is initialized to 0.

$$\begin{aligned} MF_i(X) \quad \leftarrow \quad & (1-\alpha) \times MF_{i-1}(X) + \\ & \alpha \times (1 - \frac{|d_i(X) - d_{i-1}(X)|}{R}). \end{aligned} \tag{2}$$

3) Received Signal strength Indication Factor (RSSIF): $RSSIF$ indicates the average signal strength. $RSSIF$ is calculated as Eq.(3) where $RxPr$ indicates the strength (in mW) of received signal, and $RXThresh$ is the threshold value of signal reception (RXThresh=$10^{-26} \times$ 50118723362727143mW). α is the smoothing factor (α= 0.7).

$$\begin{aligned} RSSIF_i(X) \quad \leftarrow \quad & (1-\alpha) \times RSSIF_{i-1}(X) + \\ & \alpha \times (1 - \frac{RXThresh}{RxPr}). \end{aligned} \tag{3}$$

D. Fuzzy logic based evaluation

As shown in Fig. 2, once the DF, MF and $RSSIF$ of a neighbor are calculated, the proposed protocol uses a fuzzy logic algorithm to evaluate the fitness value of the neighbor as being a MPR node. Fuzzy logic [7] deals with approximate concept of factors and imprecisely expresses the information. Since fuzzy logic can handle approximate reasoning which is similar to human reasoning, it has been widely accepted in industrial communities and considered in many applications including communication protocols [8]. The typical fuzzy logic based system consists of 3 steps: 1) input, 2) process, AND 3) output. In the input step, numeric values are converted into linguistic variables. In the process step, IF-THEN form logical rules are applied to fuzzy variables to get the linguistic results. In the output step, the linguistic results are converted to a numeric value.

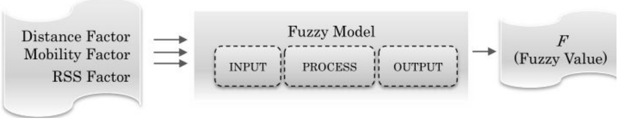

Fig. 2. Fuzzy logic based system.

1) INPUT: The protocol converts the numerical values of DF, MF and RSSIF into fuzzy linguistic variables by using the corresponding predefined variables and membership functions as shown in Fig. 3, Fig. 4 and Fig. 5.

In Fig. 3, Distance membership function estimates the degree of DF value. When DF is 0.3, the corresponding linguistic variables are {Small: 0.4, Medium: 0.6, Large: 0}. The membership functions for MF and RSSIF are defined in Fig. 4 and Fig. 5 respectively.

2) PROCESS: To obtain the linguistic results for given DF, MF and RSSIF, IF-THEN rules in Table I are applied.

In Table I, Rule1 is expressed as follows.

IF *Distance* is Large, *Mobility* is Slow and *Signal Strength* is Good **THEN** *Rank* is Perfect.

In a rule, the IF part is called the "antecedent" and the THEN part is called the "consequent." Since there are multiple

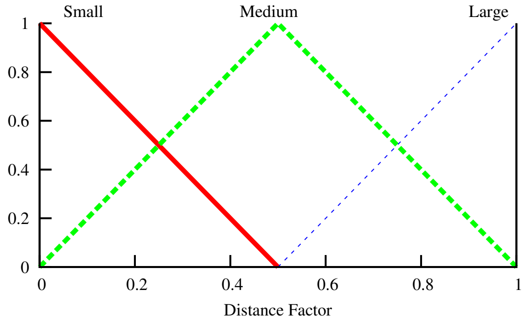

Fig. 3. Distance membership function.

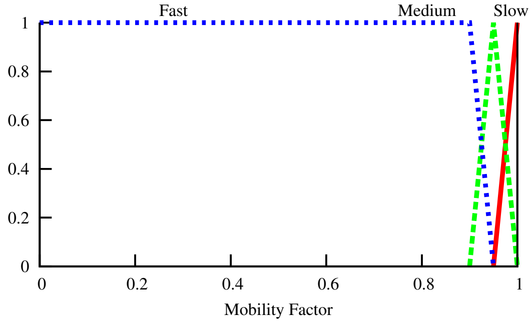

Fig. 4. Mobility membership function.

TABLE I
RULE BASE

	Distance	Mobility	Signal Strength	Rank
Rule1	Large	Slow	Good	Perfect
Rule2	Large	Slow	Medium	Good
Rule3	Large	Slow	Bad	Unpreferable
Rule4	Large	Medium	Good	Good
Rule5	Large	Medium	Medium	Acceptable
Rule6	Large	Medium	Bad	Bad
Rule7	Large	Fast	Good	Unpreferable
Rule8	Large	Fast	Medium	Bad
Rule9	Large	Fast	Bad	VeryBad
Rule10	Medium	Slow	Good	Good
Rule11	Medium	Slow	Medium	Acceptable
Rule12	Medium	Slow	Bad	Bad
Rule13	Medium	Medium	Good	Acceptable
Rule14	Medium	Medium	Medium	Unpreferable
Rule15	Medium	Medium	Bad	Bad
Rule16	Medium	Fast	Good	Bad
Rule17	Medium	Fast	Medium	Bad
Rule18	Medium	Fast	Bad	VeryBad
Rule19	Small	Slow	Good	Unpreferable
Rule20	Small	Slow	Medium	Bad
Rule21	Small	Slow	Bad	VeryBad
Rule22	Small	Medium	Good	Bad
Rule23	Small	Medium	Medium	Bad
Rule24	Small	Medium	Bad	VeryBad
Rule25	Small	Fast	Good	Bad
Rule26	Small	Fast	Medium	VeryBad
Rule27	Small	Fast	Bad	VeryBad

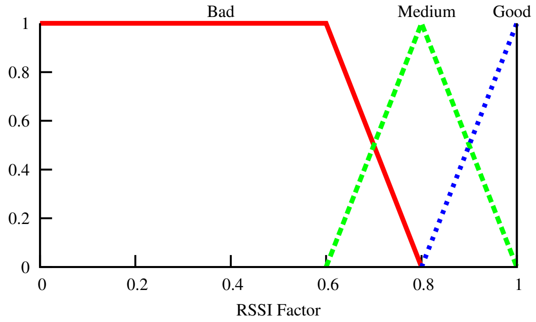

Fig. 5. RSSI membership function.

rules applying at the same time, we have to combine their evaluation results. Here we use the Min-Max method. In the Min-Max method, for each rule, the minimal value of the antecedent is used as the final degree. When combining different rules, the maximal value of the consequents is used.

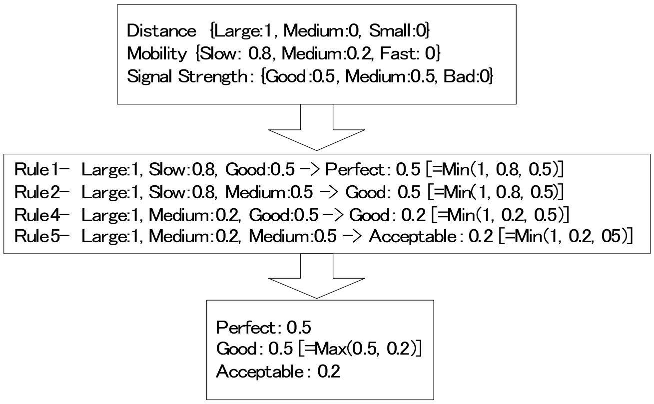

Fig. 6. An example for fuzzy rule evaluations.

As shown in Fig. 6, we assume a neighbor node's distance, mobility and RSSI factors belong to the corresponding linguistic variables as {Large:1, Medium:0, Small:0},{Slow:0.8, Medium:0.2, Fast:0},{Good:0.5, Medium:0.5, Bad:0} respectively. In this case, these fuzzy sets would match Rule1, Rule2, Rule4 and Rule5. For Rule1, the degree for {Large} (Distance) is 1, the degree for {Slow} (Mobility) is 0.8 and the degree for {Good} (Signal Strength) is 0.5. In the Min-Max method, we take the minimal value of antecedent members and therefore the degree of the antecedent will be 0.5. Similarly, the degrees of the antecedents for Rule2, Rule4 and Rule5 will be 0.5, 0.2 and 0.2 respectively. As both Rule2 and Rule4 lead to the Rank {Good}, we take the maximal value of their consequents and therefore the degree of the Rank Good will be 0.5. In this way, all rules are combined to give a fuzzy result.

3) OUTPUT: In the last step, output membership function and corresponding membership degrees are used to get the final numeric value which expresses how suitable the 1-hop neighbor node is to be a MPR node. We use the output membership function defined in Fig. 7 and Mean of Maximum (MoM) method to get the final numerical result. A neighbor node which has a higher final numerical value is more likely to be chosen as a MPR node.

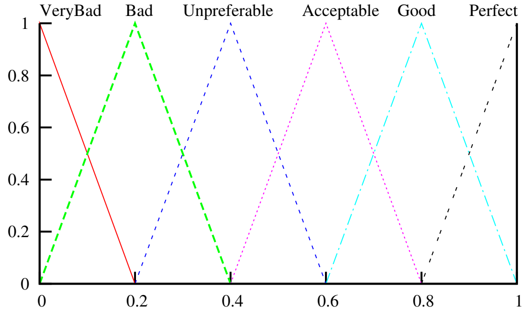

Fig. 7. Output membership function.

E. MPR selection algorithm

When a node comes to select MPRs, it chooses the best 1-hop neighbors by looking through fuzzy evaluation results. A higher value expresses the more trustful condition of the 1-hop neighbor. As shown in Fig. 8, the proposed protocol chooses MPRs one by one until all 2-hop neighbors can be covered by the selected MPRs.

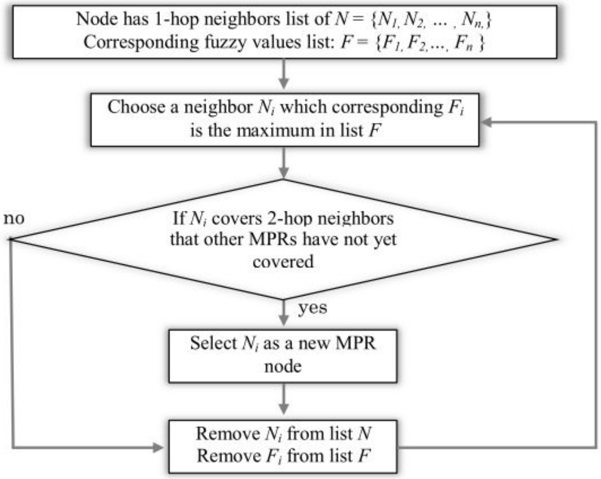

Fig. 8. MPR selection algorithm.

F. Routing table calculation algorithm

The proposed protocol uses MPR neighbors for the generation (or update) of 1-hop routes. Non-MPR neighbors and 2-hop neighbors are discussed by their link costs. For the destinations which are located beyond 2-hop distance, Topology Table is used (the same as the original OLSR). Here the link cost between node S and its 1-hop neighbor D can be expressed by value $\frac{1}{\mathrm{F_{SD}}}$ where $\mathrm{F_{SD}}$ is the fuzzy evaluation value for the link. The smaller value of link cost can imply the better link condition because $\mathrm{F_{SD}}$ implies the reliability of the 1-hop neighbor node. For a multi-hop link, the link cost is calculated as by adding all fuzzy evaluation values of direct links constituting the route. As shown in Fig. 9, the quality for the path S→X→D is $\frac{1}{\mathrm{F_{SX}}} + \frac{1}{\mathrm{F_{XD}}}$. The node S chooses the route which has the minimal link cost by comparing the path S→X→D (link cost: $\frac{1}{\mathrm{F_{SX}}} + \frac{1}{\mathrm{F_{XD}}}$), S→D (link cost: $\frac{1}{\mathrm{F_{SD}}}$), and S→Y→D(link cost: $\frac{1}{\mathrm{F_{SY}}} + \frac{1}{\mathrm{F_{YD}}}$).

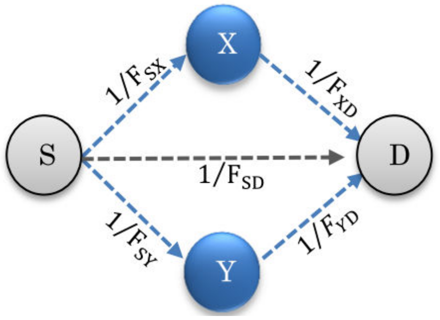

Fig. 9. Link quality estimation.

The routing table calculation takes 3 steps: a) the distance-1 (1-hop) route calculation for strictly connectable destinations, b) the distance-2 (2-hop) route calculations that need to be relayed through a neighbor node, and c) the longer (more than 2-hop distance) route calculation. Note that routing table calculation happens when a node detects topology changes by receiving Hello messages or TC messages. The calculation steps are as follows.

MPR neighbors are accessed through distance-1 routes. Non-MPR neighbors are discussed by their link costs. It is possible that some non-MPR neighbors are better to be accessed through other 1-hop neighbors. When non-MPR neighbor's link cost is smaller than alternative up-to 2-hop links, non-MPR neighbor is allowed to be added in distance-1 route. Otherwise, the path which has the smallest link cost will be used. For longer distance route, the proposed protocol works the same as the original OLSR. However, since each node can select better MPRs, the proposed protocol can choose the better routes.

IV. SIMULATION RESULTS

We used QualNet 4.5 [9] to conduct simulations. The simulation parameters are shown in Table IV. In the following results, the error bars indicate the 95% confidence intervals.

TABLE II
SIMULATION ENVIRONMENT

Topology	1200 m × 500 m
Mobility generation	Random waypoint model
Number of nodes	10 – 60
Path loss Model	Two-Ray
Fading Model	Rayleigh
FADING-MAX-VELOCITY	10
SAMPLING-RATE	1000
BASE-DOPPLER-FREQUENCY	30
NUMBER-OF-GAUSSIAN-COMPONENTS	16384
MAC	IEEE 802.11 MAC (11 Mbps)
Traffic flows	5 CBR flows, 512 bytes, 4kbps
Simulation time	130 sec.

A. *Results for stationary networks*

Fig. 10 shows the packet delivery ratio for various numbers of nodes in stationary networks. The proposed protocol can provide up to 19% higher packet delivery ratio than the original OLSR. This is due to the efficient MPR selection algorithm which takes account of received signal strength. The routing algorithm considering the link cost from the multi-hop perspective also contributes to the better performance. As we can see from Fig. 11 and Fig. 12, since the proposed protocol may use a longer route (as compared with OLSR) depending on the link quality, the average end-to-end delay is sometimes higher than OLSR. However, this can be compensated by the improvement of the packet delivery ratio.

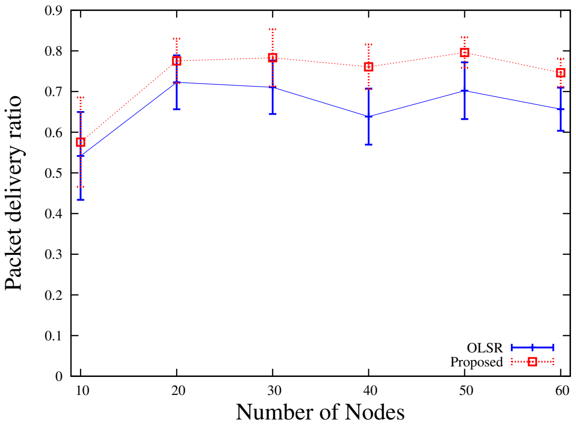

Fig. 10. Packet delivery ratio for various numbers of nodes in stationary networks.

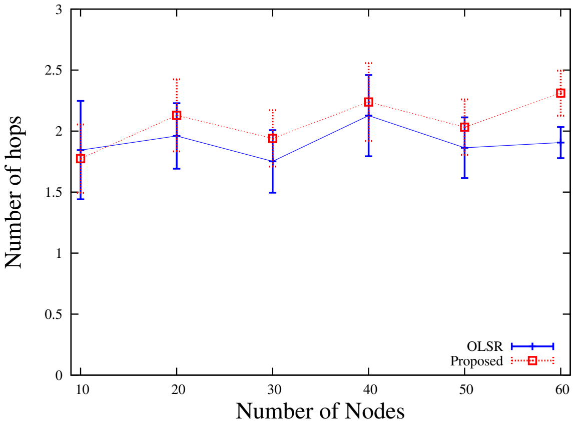

Fig. 11. Number of hops for various numbers of nodes in stationary networks.

B. *Results for various numbers of nodes in mobile networks*

In this simulation, we used random waypoint model for the mobility generation. The maximum velocity was 20 m/s. Fig. 13 shows the packet delivery ratio for various numbers of nodes. The proposed protocol shows the highest packet delivery ratio in various numbers of nodes. As shown in Fig. 14 and Fig. 15, the proposed protocol uses a slightly longer route, which results in a longer end-to-end delay. However, even in a high density network (when the number of nodes is 60), the end-to-end delay of 64 ms is acceptable for most applications. The significant effect of node density on the end-to-end delay of the proposed protocol is due to the overhead of HELLO messages. When the node density is high, the periodical HELLO messages can affect the MAC layer contention time at each node dramatically.

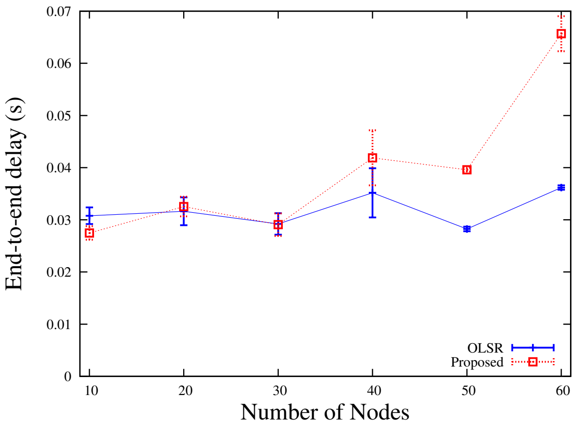

Fig. 12. End-to-end delay for various numbers of nodes in stationary networks.

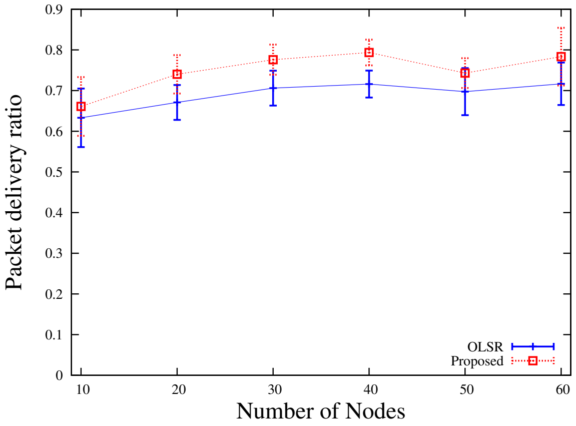

Fig. 13. Packet delivery ratio for various numbers of nodes in mobile networks.

C. *Results for various velocities*

We evaluated the protocol for various velocities. The number of nodes was 30. As shown in Fig. 16, the proposed protocol shows a significant improvement over the original OLSR. The average route length of the proposed protocol is larger than OLSR (see Fig. 17). However, as we can see from Fig. 18, the proposed protocol still can provide a low delay.

V. CONCLUSIONS AND FUTURE WORKS

Based on OLSR, we proposed a protocol which employs a fuzzy logic into MPR selection. Considering the features of mobile ad hoc networks such as the high mobility and lossy

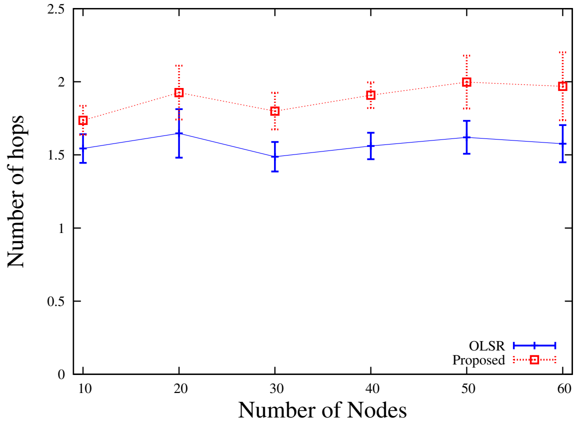

Fig. 14. Number of hops for various numbers of nodes in mobile networks.

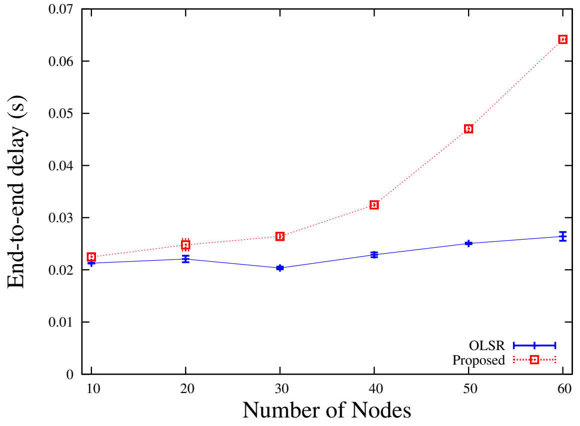

Fig. 15. End-to-end delay for various numbers of nodes in mobile networks.

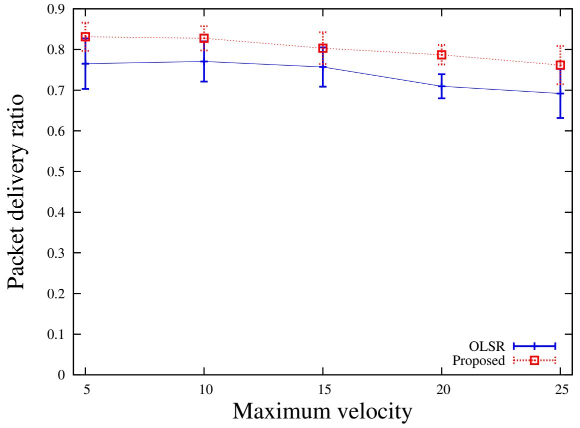

Fig. 16. Packet delivery ratio for various maximum velocities.

channels, the fuzzy logic is employed to take account of inter-node distance, node movement and received signal strength. The simulation results in QualNet showed that the proposed protocol can provide a significantly higher packet delivery ratio as compared with the original OLSR. In future work, we will evaluate the protocol's performance for TCP flows.

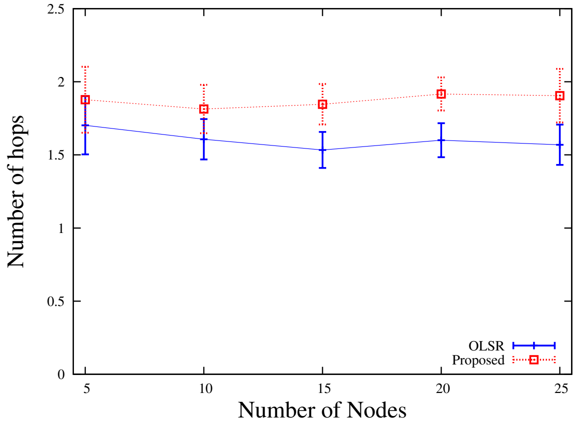

Fig. 17. Number of hops for various maximum velocities.

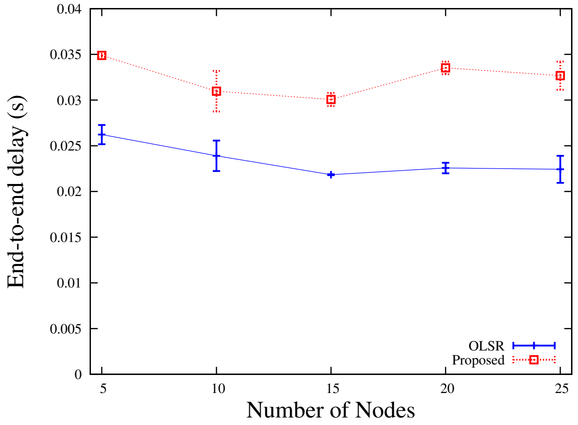

Fig. 18. End-to-end delay for various maximum velocities.

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