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Fuzzy Logic for Multi-Hop Broadcast in Vehicular Ad Hoc Networks

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1. Introduction

A Vehicular Ad hoc Network (VANET) is a form of mobile ad hoc network in which vehicles are equipped with wireless communication devices. Vehicular ad hoc networks have been attracting the interest of both academic and industrial communities on account of their important role in Intelligent Transportation Systems (ITS). VANETs are expected to be able to significantly reduce the number of road accidents. When vehicles travel at a high speed on roads, drivers have very little time to react to the vehicle in front of them. By using vehicular ad hoc networks, emergency information can be propagated along the road to notify drivers ahead of time so that necessary actions can be taken to avoid accidents. Vehicular ad hoc networks also make the driving more efficient by disseminating traffic warning information and service information.

In this chapter, we consider VANET broadcast protocols which work as a basis of many vehicular applications especially safety applications. Providing reliable and efficient multi-hop broadcast in vehicular ad hoc networks is very challenging. First, in vehicular ad hoc networks, vehicles are usually deployed in a dense manner. Therefore, a simple broadcast scheme cannot work well because of redundant broadcasts. Second, wireless communications are unreliable and vehicles can move at a high speed. Consequently, it is difficult to reduce the redundant broadcast while maintaining a high packet dissemination ratio.

As a solution, we explain an approach which uses a fuzzy logic to enhance multi-hop broadcast in vehicular ad hoc networks. Due to the high node density, vehicle movement and fading feature of wireless communications, providing a reliable and efficient multi-hop broadcast in vehicular ad hoc networks is still an open research topic. Using only a subset of neighbor nodes to relay broadcast messages is a main concept for providing efficiency. Meanwhile, in order to ensure a high reliability, multiple metrics of inter-vehicle distance, node mobility and signal strength should be jointly considered in the relay node selection. However, these metrics conflict with each other and these conflicts depend on the vehicle mobility, vehicle distribution and fading condition. The mathematical model of the optimal relay problem is complex to derive and a solution based on it would be too expensive for practical application. Therefore, we employ fuzzy logic to handle these imprecise and uncertain information. We use a fuzzy logic based method to select relay nodes by jointly considering inter-vehicle distance, node mobility and signal strength. The selected relay nodes can provide a reliable data forwarding with a high efficiency. In this chapter, we give a detailed description of the fuzzy logic based method with simulation results.

The basic idea of the approach has been published by IEEE (Wu et al. (2010)). However, in this chapter, we use a more realistic model to evaluate the approach and present our new simulation results. We explain the approach with new and more detailed information.

2. Multi-hop broadcast in vehicular ad hoc networks

The simplest way to disseminate information is flooding. In the flooding, each node rebroadcasts a packet upon the first reception. Obviously, in a high-density network, the flooding introduces too many redundant broadcasts and consequently incurs collisions and results in a low dissemination rate. There have been a lot of protocols to reduce the redundant broadcasts in a high-density network. These protocols can be classified into two categories of sender-oriented protocols and receiver-oriented protocols. In the sender-oriented protocols, a sender node specifies relay nodes. In contrast, in the receiver-oriented protocols, upon reception of a message, a receiver node determines own action (whether rebroadcast the message or not) in an autonomous manner.

2.1 Receiver-oriented protocols

Several receiver based broadcast protocols have been proposed. Wisitpongphan & Tonguz (2007) have proposed three broadcast schemes: weighted p-persistence, slotted 1-persistence, and slotted p-persistence schemes. In these protocols, upon reception of a message, a node calculates a broadcast probability according to the distance from the sender node. Generally, a larger distance from the sender node results in a higher broadcast probability. Suriyapaiboonwattana et al. (2009) have proposed a protocol which uses an adaptive wait time and adaptive probability to trigger the rebroadcast. Slavik & Mahgoub (2010) have proposed a protocol in which all nodes rebroadcast a received message with a certain probability. Mylonas et al. (2008) have proposed a Speed Adaptive Probabilistic Flooding algorithm to determine the rebroadcast probability according to vehicle speed. However, in the receiver-based protocols, each node determines whether rebroadcast or not in an autonomous manner. Therefore, redundant broadcasts cannot be eliminated entirely.

2.1.1 Weighted p-persistence, slotted 1-persistence and slotted p-persistence scheme

Wisitpongphan & Tonguz (2007) have proposed three probabilistic and timer-based broadcast suppression techniques. They are weighted p-persistence, slotted 1-persistence and slotted p-persistence Scheme.

In the weighted p-persistence scheme, upon reception of a packet from node t, node r checks the packet ID and rebroadcasts with probability p_{tr} if node r receives the packet for the first time. Otherwise, the node discards the packet. The probability, p_{tr}, is calculated on a per packet basis using

$$p_{tr} = \frac{D_{tr}}{R}, \tag{1}$$

where D_{tr} is the relative distance between nodes t and r, R is the average transmission range. The larger the D_{tr}, the higher the probability will be.

In slotted 1-persistence scheme, upon reception of a packet, a node checks the packet ID. If the node receives the packet for the first time and fails to detect any rebroadcast from other nodes in an assigned time slot $T_{S_{tr}}$, the node rebroadcasts the packet. If the node can detect a rebroadcast of the packet from any other nodes, the node discards the packet. $T_{S_{tr}}$ is calculated as

$$T_{S_{tr}} = S_{tr} \times \tau, \quad (2)$$

where τ is the estimated one-hop delay, which includes the medium access delay and propagation delay. S_{tr} is the assigned slot number, which is calculated by

$$S_{tr} = \lceil N_s(1 - \frac{min(D_{tr}, R)}{R})\rceil, \quad (3)$$

where N_s is the number of slots.

Similar to slotted 1-persistence scheme, in the slotted p-persistence scheme, upon reception of a packet, a node checks the packet ID. If the node receives the packet only once in the assigned time slot $T_{S_{tr}}$ which is calculated as Eq. (2), the node rebroadcasts with the predetermined probability p. Otherwise, the node discards the packet.

2.2 Sender-oriented protocols

In the sender-oriented protocols, since the sender node specifies relay nodes, the redundant broadcasts can be minimized. The relay node selection method directly affects the performance of a sender-oriented protocol. Generally, the relay node selection is based on the information collected from the exchange of hello messages. Qayyum et al. (2002) have proposed a multipoint relay (MPR) broadcast scheme (here we call MPR Broadcast) in which relay nodes are selected using two-hop neighbor information. Djedid et al. (2008) have proposed a broadcast protocol which selects relay nodes based on Connected Dominating Set. However, these protocols do not consider node mobility in the relay node selection. As a result, the selected relay node can become sub-optimal and can lose the message due to the node movement.

In our previous work (Wu et al. (2010)), we have proposed a relay node selection which considers the additional radio coverage and node movement (here we call EMPR Broadcast). However, EMPR Broadcast does not consider the fading feature of wireless channels. In a wireless channel, a node can receive a hello message from a neighbor which is at a distance where stable communication is impossible. If the neighbor node is selected as a relay node, a packet loss would occur at the neighbor node.

Sahoo et al. (2009) have proposed BPAB, a Binary Partition Assisted emergency Broadcast protocol for vehicular Ad hoc networks. BPAB intends to use the farthest node to relay messages. However, in a fading channel, the farthest node can lose the messages. Therefore, we have to choose the nodes which have stable signal strength as relay nodes. In short, multiple metrics of inter-vehicle distance, mobility and signal strength should be considered in the relay node selection.

2.2.1 MPR

Qayyum et al. (2002) have proposed a multipoint relay (MPR) broadcast scheme (here we call MPR Broadcast). MPR can substantially reduce the message overhead as compared to the flooding. In MPR broadcast, each node selects a set of its neighbor nodes as “multipoint relays” (MPR). Only the selected MPR nodes are responsible for forwarding the messages. The neighbors of node N which are not in its MPR set, receive and process broadcast messages but do not retransmit broadcast messages received from node N. MPR broadcast provides an efficient mechanism for disseminating messages by reducing the number of transmissions.

Every node attaches its one hop neighbors to the hello messages. In this way, every node is aware of its two-hop neighbors. Each node selects its MPR set from its one-hop neighbors. This set is selected such that these nodes cover (in terms of radio range) all two-hop neighbor nodes. The MPR set of N, denoted as $MPR(N)$, is then an arbitrary subset of the one-hop neighbor of N. $MPR(N)$ satisfies the following condition: every node in the two-hop neighborhood of N must have a link towards $MPR(N)$. The smaller a MPR set (in term of the number of nodes in the set), the less the message overhead.

The following is a heuristic for the selection of MPR nodes.

1. Start with an empty multipoint relay set $MPR(x)$.
2. First select those one-hop neighbor nodes in $N(x)$ as multipoint relays which are the only neighbor of some node in $N^2(x)$, and add these one-hop neighbor nodes to the multipoint relay set $MPR(x)$.
3. While there still exist some node in $N^2(x)$ which is not covered by $MPR(x)$:
   (a) For each node in $N(x)$ which is not in $MPR(x)$, compute the number of nodes that the node covers among the uncovered nodes in the set $N^2(x)$.
   (b) Add the node which has the maximal this number to $MPR(x)$.

MPR can optimize the message dissemination by minimizing the number of messages flooded in the network. The technique is particularly suitable for large and dense networks. However, MPR cannot be used in vehicular ad hoc networks without enhancement because MPR does not consider node mobility at all. In vehicular ad hoc networks, because of node movement, the neighbor information can be imprecise, resulting in the selected relay nodes fail to receive the packets.

2.2.2 EMPR

In addition to the radio coverage, EMPR (Wu et al. (2010)) considers node mobility in the relay node selection. EMPR algorithm introduces predicted MPR fitness (PMF) to evaluate a node whether it is suitable for relaying broadcast packet or not. A sender node selects the neighbor which has the maximal PMF as a relay node from the possible candidate nodes.

Upon reception of a hello message from node x, sender node s calculates the corresponding multipoint relay fitness ($MF(x)$) as

$$MF_i(x) = \frac{|AC_i(x)|}{|N_i(s) \cup N_i(x)|} \tag{4}$$

where i indicates the current value. $N_i(x)$ denotes neighbor set of node x, $|N_i(x)|$ denotes number of x's one hop neighbors. $AC(x)$ is defined as

$$AC(x) = \overline{N(s)} \cap N(x). \tag{5}$$

Eq. (4) could give a higher value for a node that has larger additional radio coverage.

In order to provide different weights to different level of movements, EMPR algorithm introduces discount rate θ which is calculated as

$$\theta = \begin{cases} \sqrt{\frac{|AC_i(x) \cap AC_{i-1}(x)|}{|AC_i(x) \cup AC_{i-1}(x)|}}, & \text{if } AC_i(x) \cup AC_{i-1}(x) \neq \phi \\ 0, & \text{otherwise,} \end{cases} \tag{6}$$

where $i-1$ indicates the previous value (the value is updated on the reception of a hello message). Eq. (6) could give a larger value for the same directed vehicles and smaller value for vehicles that moving toward opposite direction. If a node x has opposite moving direction to the sender, corresponding θ will be smaller than other vehicles which have the same direction because its additional radio coverage ($AC(.)$) is changing frequently.

Upon reception of a hello from its neighbor, a sender node updates a neighbor's PMF as follows.

$$PMF_i(x) \leftarrow (1-\mu)PMF_{i-1}(x) + \mu \times \theta \times MF_i(x). \tag{7}$$

Every node maintains a PMF ($PMF_{i-1}(x)$) and AC ($AC_{i-1}(x)$) for every one-hop neighbor. In Eq. (7), the $PMF_{i-1}(x)$ is initialized to 0. Similarly, $AC_{i-1}(x)$ is initialized to ϕ in Eq. (6). The sender node uses these values, the current MF ($MF_i(x)$) and AC ($AC_i(x)$) to calculate the latest PMF ($PMF_i(x)$) as shown in Eq. (6) and Eq. (7). The node then updates the $PMF_{i-1}(x)$ and $AC_{i-1}(x)$. $PMF(x)$ is reset to zero if the sender fails to hear any hello message from node x in three times the hello interval.

In Ref. (Wu et al. (2010)), a retransmission method also has been proposed. However, in this chapter, we do not consider the retransmission issue.

2.3 Challenges

Receiver-oriented approaches cannot reduce the redundant broadcasts entirely. As a result, it is difficult to guarantee a high data dissemination ratio. In this chapter we consider using a sender-oriented approach. However, in the sender-oriented approach, when a relay node fails to receive a packet, the data delivery fails. Therefore, selecting efficient and reliable relay nodes is the most important issue for sender-oriented protocols.

3. Why fuzzy logic

In vehicular ad hoc networks, redundant rebroadcasts incur packet collisions and a higher end-to-end delay due to the increase of MAC layer contention time. It is important to reduce the broadcast redundancy by selecting a small subset of nodes to relay a broadcast packet. However, the relay node selection uses the information collected from the exchange of hello messages. In a highly mobile network, the selected relay node can move out the transmission range of the sender node. Moreover, a node can receive a hello message from a neighbor which is at a distance where stable communication is impossible. If an inappropriate neighbor node is selected as a relay node, the neighbor node fails to receive the message.

Therefore, in the relay node selection, multiple metrics of inter-vehicle distance, node mobility and signal strength should be considered jointly. However, it is difficult to establish a satisfactory relay node evaluation criterion for the following reasons. First, the network information (inter-vehicle distance, node mobility and signal strength) known by each node is inaccurate, incomplete and imprecise. Second, since these metrics may conflict with each other, it results in uncertainty.

As shown in Fig. 1, if we select the farthest node as a relay node, it minimizes the number of relays (efficiency up). But that relay node may lose the packet because the signal is weak (reliability down). Moreover, due to the node movement, the relay node might move out the transmission range of the sender node. These conflicts depend on the vehicle mobility, vehicle distribution and fading condition. Therefore, the mathematical model of the optimal relay problem is complex to derive and a solution based on it would be too expensive for practical application. Fortunately, fuzzy logic can handle imprecise and uncertain information. Therefore, we use a fuzzy logic based method to identify those relay nodes that will give the best results.

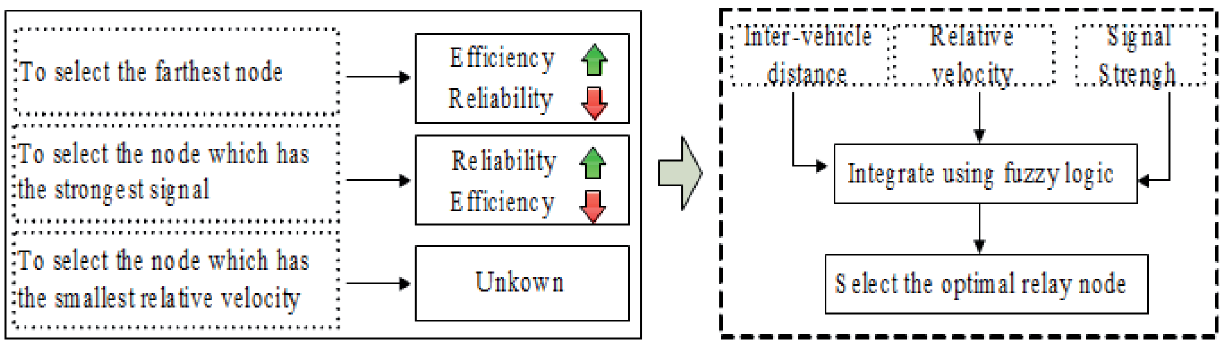

Fig. 1. Using fuzzy logic to consider multiple metrics jointly.

In fuzzy set theory (Klir et al. (1997)), elements have degrees of membership. Fuzzy set theory represents incomplete or imprecise information by defining set membership as a possibility distribution. Based on fuzzy set theory, fuzzy logic deals with the concept of approximate rather than precise factors. For example, we can define a person's height as being 0.5 "high" and 0.5 "low", rather than "completely high" or "completely low". Fuzzy logic has been broadly used for industrial communities due to its efficient handling of approximate reasoning which is similar to human reasoning. In contrast to numerical values in mathematics, fuzzy logic uses non-numeric linguistic variables to express the facts. Fuzzy logic uses fuzzy membership functions to represent the degrees of a numerical value belonging to linguistic variables.

Typically, a fuzzy logic based system consists of three steps: input, process and output steps. In the input step, numerical values are converted to linguistic variables. The process step collects fuzzy rules which are defined in the form of IF-THEN statements and applies the rules to get the result in a linguistic format. The output step converts the linguistic result into a numerical value.

A fuzzy logic based system is flexible because the system can satisfy different requirements by tuning the fuzzy membership function and fuzzy rules. A flexible design is very important for vehicular ad hoc networks due to the variance of channel status and vehicle movement for different road conditions.

4. A multi-hop broadcast protocol based on fuzzy logic

In this section, we present an approach which uses a fuzzy logic to enhance multi-hop broadcast in vehicular ad hoc networks.

4.1 Protocol design

The protocol uses a sender-oriented approach. As shown in Fig. 2. In order to reduce rebroadcast redundancy in high-density networks, the protocol uses only a subset of nodes in the network to relay broadcast packets. We assume every node knows its own position which can be acquired from GPS like positioning services. Vehicles exchange information through hello messages. Every vehicle places its own position information to hello messages and therefore vehicles know positions of their neighbors. A neighbor node is removed from the neighbor list if a node fails to receive any hello message from the neighbor node in 3 times the hello interval. The hello interval is set to 1 second. Before broadcasting a packet, a sender node attaches the identifiers (IP addresses) of the relay nodes to the packet. Upon reception of a packet, a node rebroadcasts the packet only if itself is included in the relay node list.

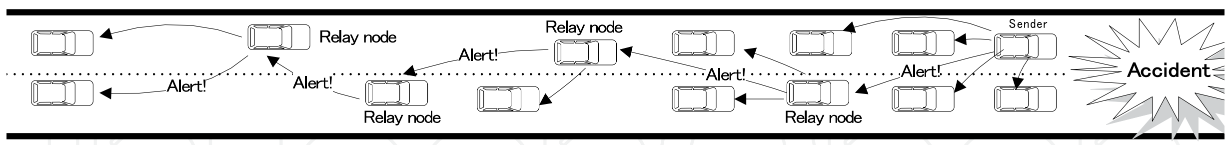

Fig. 2. Multi-hop broadcast by using relay nodes.

Every node maintains a distance factor, mobility factor and signal strength factor for each neighbor. These factors are updated upon reception of a hello message. Before sending a data packet, each node evaluates one-hop neighbors by using fuzzy logic to combine these factors. Based on the evaluation result, the nodes which have high evaluation values are selected as relay nodes.

4.2 Broadcast zone and the number of relay nodes

The sender node specifies relay nodes. It is important to ensure selected relay nodes reaching all intended receivers while minimizing the number of rebroadcasts. To solve this issue, the concept of "broadcast zone" is introduced. In the protocol, a sender node selects one relay node from each broadcast zone.

A sender node first groups neighbor vehicles according to [road_no, sender_pos, direction]. As shown in Fig. 3, "road_no" denotes the road number, "sender_pos" denotes the sender position and "direction" can be "outbound" or "inbound." We call a triad [road_no, sender_pos, direction] a "broadcast zone". For example, the triad [1, (x, y, z), outbound] shows the area which is on the road No.1 and in the "outbound" direction of position (x, y, z).

We note that "outbound" and "inbound" are predefined for each road. For a loop-free road, since the start point and end point can be defined, we define the direction from the start point to the end point as "outbound," and define the direction from the end point to the start point as "inbound." For a loop road, we define the clockwise direction as "outbound" and the counter-clockwise direction as "inbound." As shown in Fig. 3, for road No.1, the direction from A to B is the outbound direction, and the direction from B to A is the inbound direction. In here, "outbound" and "inbound" depend on the position of the vehicles but be independent to the driving directions of the vehicles. We say V1 is at the outbound direction of node V2. In contrast, V2 is at the inbound direction of node V1.

Before broadcasting a data message, the source node specifies the intended area as a list of broadcast zones. The sender node selects one relay node in each of the specified broadcast zones. In the example in Fig. 3, to disseminate information in all directions, node S has to select 4 relay nodes.

In a large scale network, we do not need to let a data message traverse through the whole network. In this case we can specify a border for each broadcast zone by specifying the most distant (from the sender node) position of the intended area. Another way is to define a life time for each message by specifying the hop count or TTL (Time To Live). In this section, without loss of generality, we consider all nodes in the network as the intended receivers.

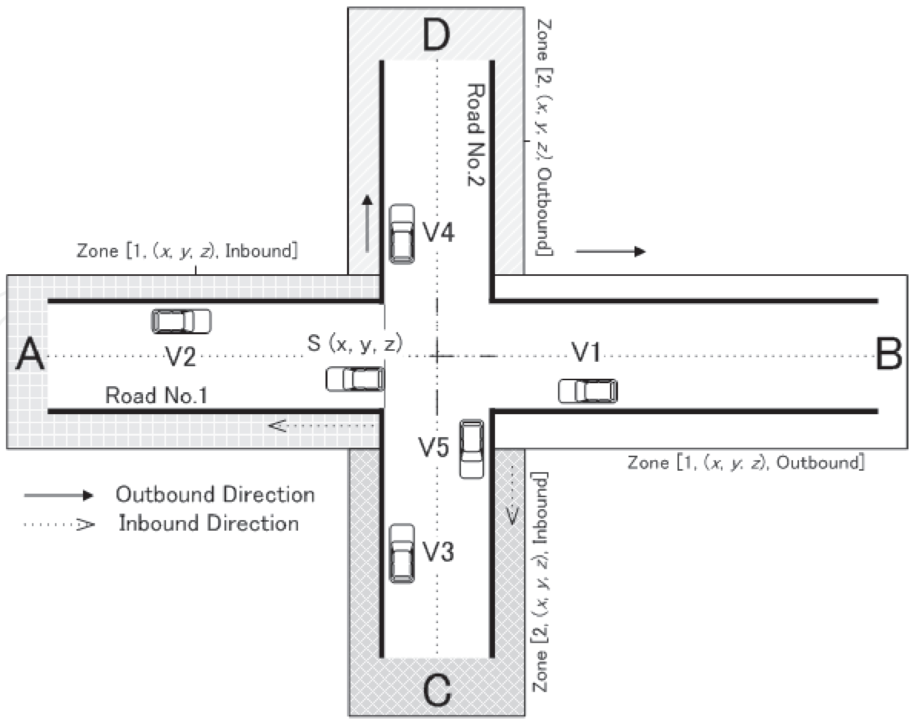

Fig. 3. A street road topology.

4.3 Neighborhood status update using hello messages

In the protocol, upon reception of a hello message from a neighbor, a node evaluates the neighbor according to the inter-vehicle distance, mobility and signal strength respectively. In this way, through exchanging hello messages, each node maintains an evaluation result for each neighbor. When selecting a relay node, these evaluation results are used.

4.3.1 Distance

Upon reception of a hello message from a neighbor X, a node calculates a Distance Factor (DF) as Eq. (8). In Eq. (8), $d(X)$ is the distance between the current node and node X. R is the average transmission range. Here we assume every node has the same transmission power and the transmission power is constant.

$$DF(X) = \begin{cases} \frac{d(X)}{\mathrm{R}}, & d(X) <= \mathrm{R} \\ 1, & d(X) > \mathrm{R} \end{cases} \tag{8}$$

Eq. (8) gives a higher value for a node which has larger distance from the sender node. When the Distance Factor is large, a message can reach the destination region with a small number of rebroadcasts. Therefore, a larger distance factor is desirable to provide a high efficiency.

4.3.2 Mobility

Upon reception of a hello message from a neighbor X, a node calculates a Mobility Factor (MF) as Eq. (9). MF indicates the mobility level of the neighbor node. Here, $d_i(X)$ is the distance between the current node and the neighbor node at time i. α is a smooth factor which is used to smooth out short-term errors. The value of α is set to 0.7 based on out experimental results. MF is initialized to 0.

$$MF(X) \leftarrow (1-\alpha) \times MF(X) + \alpha \times (1 - \frac{|d_i(X) - d_{i-1}(X)|}{R}). \quad (9)$$

As shown in Eq. (9), the lower the relative movement, the larger is the mobility factor. Since each neighbor is evaluated periodically (upon reception of a hello message), a large mobility factor is required to ensure a specified relay node is still in the transmission range of the sender node when a data packet is sent at the sender node.

4.3.3 Signal strength

Upon reception of a hello message from a neighbor X, a node calculates a Received Signal Strength Indication Factor (RSSIF) as Eq. (10). In Eq. (10), RxPr denotes the received signal power, and RXThresh is the reception threshold. RSSIF indicates the average signal strength of the neighbor node. Here RSSIF is initialized to 0.

$$RSSIF(X) \leftarrow (1-\alpha) \times RSSIF(X) + \alpha \times (1 - \frac{RXThresh}{RxPr}). \quad (10)$$

Eq. (10) calculates the average signal strength from a neighbor node. In here, we use the RSSI factor to estimate the received signal strength at the neighbor node. A high RSSIF factor can ensure the packet reception at the neighbor node when the neighbor node is selected as a relay node.

4.4 Relay node selection based on fuzzy logic

4.4.1 Procedure

As mentioned above, each node evaluates its neighbors in term of distance, mobility and signal strength by exchanging hello messages. When there is a need to send a packet, a node employs the fuzzy logic to calculate an average relay fitness value for each neighbor based on the neighbor's distance, mobility and signal strength. The node then selects a relay node for each broadcast zone.

For each broadcast zone, a sender node selects the node that has maximal fitness value to relay the packet. The calculation steps for the relay fitness value for each neighbor are as follows.

- **Fuzzification** Use predefined linguistic variables and membership functions to convert the distance factor, mobility factor and RSSI factor to corresponding fuzzy values.
- **Mapping and combination of IF/THEN rules** Map the fuzzy values to predefined IF/THEN rules and combine the rules to get the rank of the neighbor as a fuzzy output value.
- **Defuzzification** Use predefined output membership function and defuzzification method to convert the fuzzy output value to a numerical value.

4.4.2 Fuzzification

"Fuzzification" is the process of converting a numerical value to a fuzzy value using a predefined fuzzy membership function. The fuzzy membership function of distance factor is defined as Fig. 4. The linguistic variables defined for the distance factor are {Large, Medium, Small}. The sender node uses the membership function and the distance factor to calculate what degree the distance factor belongs to {Large, Medium, Small}. As shown in Fig. 4, when the distance factor is 0.2, we get a fuzzy value {Large:0, Medium:0.4, Small:0.6}. Fig. 5 shows

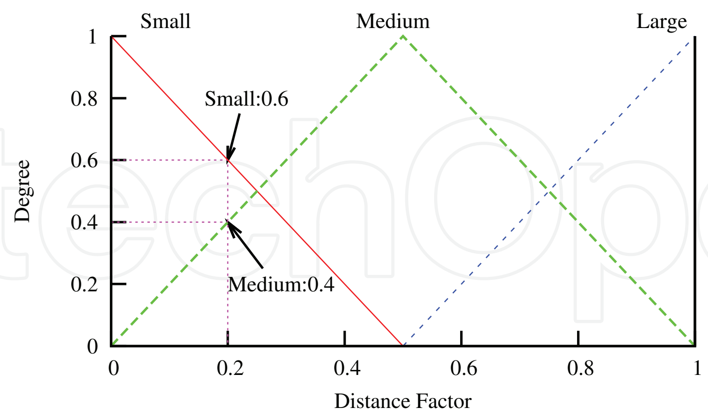

Fig. 4. Distance membership function.

the fuzzy membership function defined for the mobility factor. The sender node uses the mobility factor and this membership function to calculate what degree the mobility factor belongs to {Slow, Medium, Fast}. Fig. 6 shows the fuzzy membership function defined for the

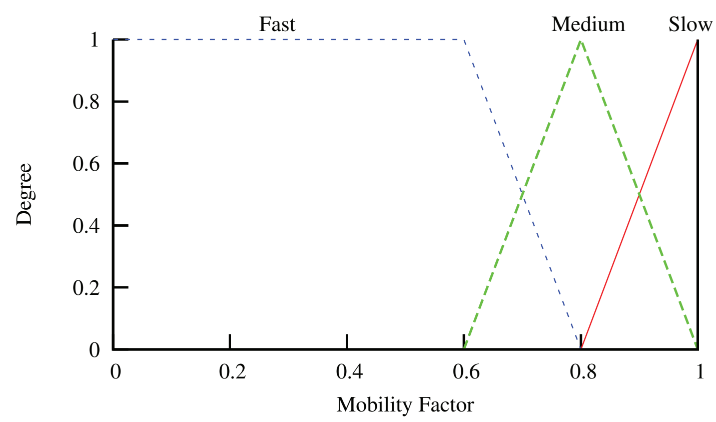

Fig. 5. Mobility membership function.

RSSI factor. The sender node uses the RSSI factor and this membership function to calculate what degree the RSSI factor belongs to {Good, Medium, Bad}.

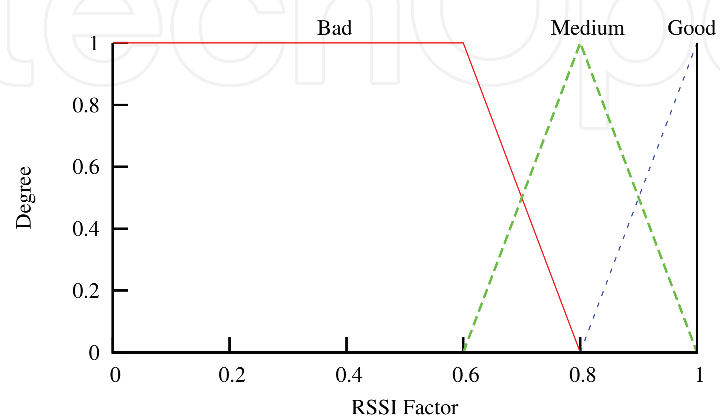

Fig. 6. Signal strength membership function.

4.4.3 Rule base

Based on the fuzzy values of distance factor, mobility factor and RSSI factor, the sender node uses the IF/THEN rules (as defined in Table 1) to calculate the rank of the node. The linguistic variables of the rank are defined as {Perfect, Good, Acceptable, NotAcceptable, Bad, VeryBad}. In Table 1, Rule1 defines the following rule. **IF** *Distance* is Large, *Mobility* is Slow and *Signal*

	Distance	Mobility	Signal Strength	Rank
Rule1	Large	Slow	Good	Perfect
Rule2	Large	Slow	Medium	Good
Rule3	Large	Slow	Bad	NotAcceptable
Rule4	Large	Medium	Good	Good
Rule5	Large	Medium	Medium	Acceptable
Rule6	Large	Medium	Bad	Bad
Rule7	Large	Fast	Good	NotAcceptable
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	NotAcceptable
Rule15	Medium	Medium	Bad	Bad
Rule16	Medium	Fast	Good	Bad
Rule17	Medium	Fast	Medium	Bad
Rule18	Medium	Fast	Bad	VeryBad
Rule19	Small	Slow	Good	NotAcceptable
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	VeryBad
Rule26	Small	Fast	Medium	VeryBad
Rule27	Small	Fast	Bad	VeryBad

Table 1. Rule Base

Strength is Good **THEN** *Rank* is Perfect.

When the distance factor is large, we can reduce the number of hops for broadcast. When the mobility is slow, the relay nodes are not likely to move out the transmission range of the sender node. A high Signal Strength can ensure a packet will be received by the relay nodes. This is why the Rank of the Rule1 is Perfect.

Compared with the Rule1, when any one of three factors (Distance, Mobility and Signal Strength) drops to the next level, we set the Rank to be “Good” (Rule2, Rule4 and Rule10). Similarly, when any two of three factors drop to the next level, we set the rank to be “Acceptable” (Rule5, Rule11 and Rule13). When any one of three factors drops to the worst level, we set the Rank to be “NotAcceptable” (Rule3, Rule7 and Rule19). The same for the case when all three factors are at the medium level (Rule 14). When two or all three factors drop to the worst level, we set the Rank to be "VeryBad" (Rule9, Rule18, Rule21, Rule24, Rule 25, Rule26 and Rule27). For other rules, we set the Rank to be "Bad" (Rule6, Rule8, Rule12, Rule15, Rule16, Rule17, Rule20, Rule22 and Rule23). In this way, we define 27 rules in total. These rules cover all possible combinations of fuzzy values in different factors.

In a rule, the IF part is called the "antecedent" and the THEN part is called the "consequent". Since there can be multiple rules applying for the same fuzzy variables, we have to combine their evaluation results. Here we use Min-Max method to match and combine the rules. In the Min-Max method, for each rule, the minimal value of antecedent is used as the final degree. When combining different rules, the maximal value of consequents is used.

For example, as shown in Fig. 7, we assume a neighbor's distance, mobility and RSSI factor 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 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 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 consequents and therefore the degree of the Rank Good will be 0.5. In this way, all rules are combined to get a fuzzy result.

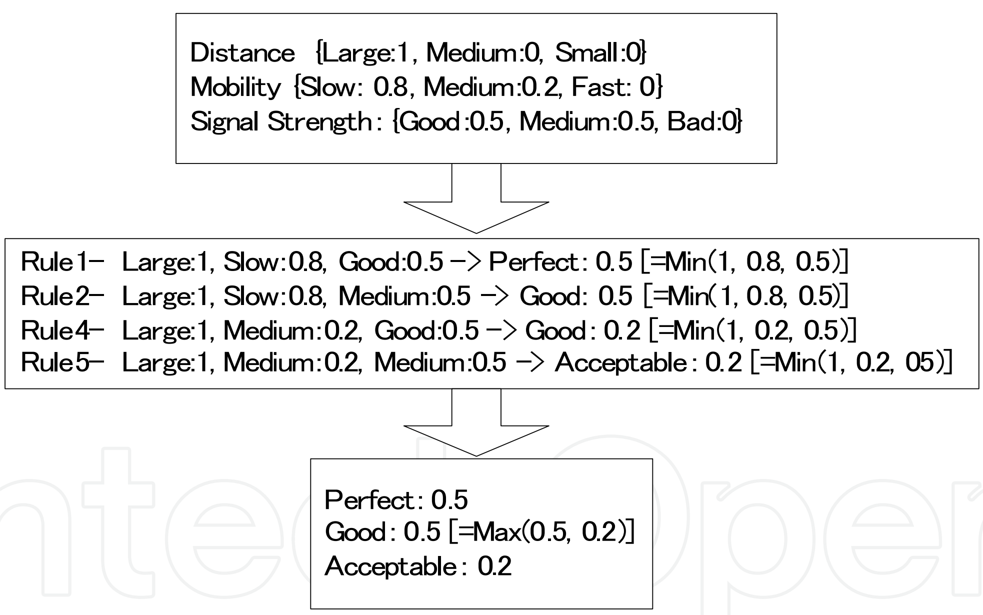

Fig. 7. An example for fuzzy rule evaluations.

4.4.4 Defuzzification

Defuzzification is used to produce a numeric result based on a predefined output membership function and corresponding membership degrees. Fig. 8 shows the defined output membership function. Here Center of Gravity (COG) method is used to defuzzify the fuzzy result.

As shown in Fig. 8, we cut the output membership function in a straight horizontal line according to the corresponding degree, and remove the top portion. For the example given

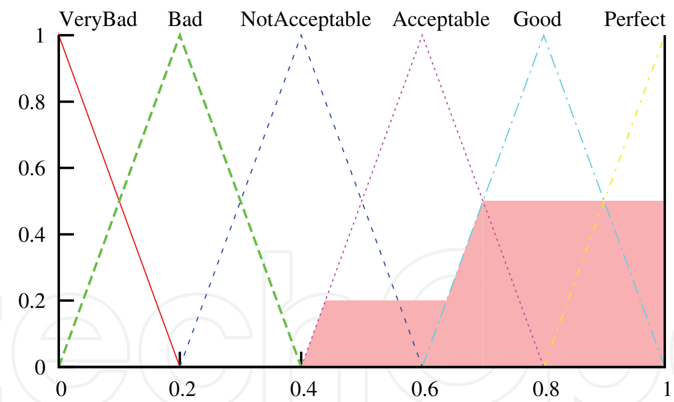

Fig. 8. Output membership function and an example for $\mu(x)$.

above, when the degree for Rank {Acceptable} is 0.2, the degree for Rank {Good} is 0.5 and the degree for Rank {Perfect} is 0.5, the result function will be as shown in Fig. 8. The center of gravity is calculated as

$$COG = \frac{\int \mu(x)xdx}{\int \mu(x)dx}, \tag{11}$$

where $\mu(x)$ is the result function and x is the value of X-axis. In this protocol, the calculated COG represents the fitness of the neighbor being a relay node. For each broadcast zone, the sender node calculates a fitness value for each neighbor node and then selects the node which has the maximal fitness value.

4.5 Simulation results

Network Simulator 2 (ns-2.34) (ns-2 (2010)) was used to conduct simulations. We used a Freeway model (Bai et al. (2003)) to generate the network topology (see Table 2). We used a freeway which has two lanes in each direction. All lanes of the freeway were 2000 m in length. The maximum allowable vehicle velocity was 40m/s. We used Nakagami propagation model. Parameters of the Nakagami model are shown in Table 3. These parameters result packet delivery ratios as shown in Fig. 9. We used these parameter values because they model a realistic wireless channel of vehicular ad hoc networks (Khan et al. (2009)).

Topology	Freeway scenario, 2000m, 4lanes
Number of nodes	100 to 600
Mobility generation	Bai et al. (2003)
Number of sources	2
Number of receivers	The number of all nodes in the network
Number of packets	50 packets at each source
Packet size	512 bytes
Data rate	10 packet per second
MAC	IEEE 802.11 MAC (2Mbps)
Propagation model	Nakagami Model
Simulation time	150 s

Table 2. Simulation Environment

Other simulation parameters were the default settings of ns-2.34. From 20s, two source nodes generated 50 packets with a rate of 10 packets per second. These two nodes (randomly

gamma0_	gamma1_	gamma2_	d0_gamma_	d1_gamma_
1.9	3.8	3.8	200	500
m0_	m1_	m2_	d0_m_	d1_m_
1.5	0.75	0.75	80	200

Table 3. Parameters of Nakagami Model

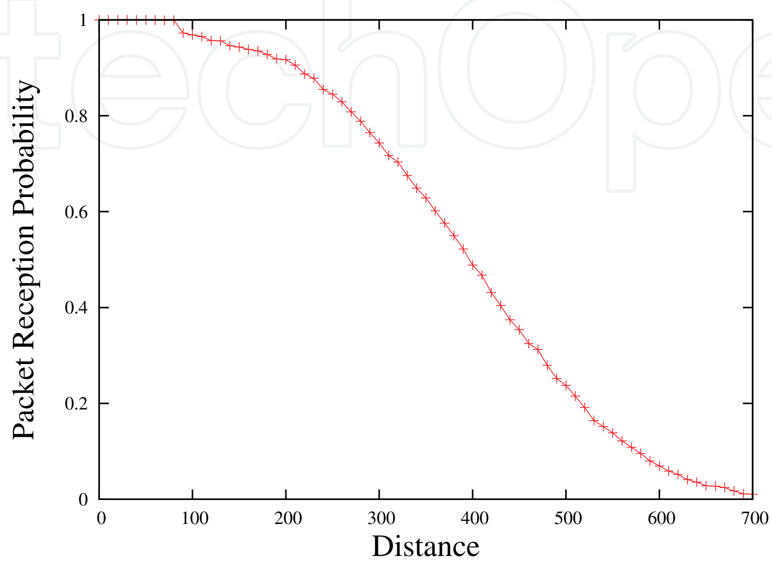

Fig. 9. Packet reception probability for various distances.

selected) were neighbors and being close to each other. This is to simulate a condition of two collided vehicles send data messages at the same time. Simulation time was 150s. We launched simulations with 50 different vehicle deployments and different vehicle movements, and analyzed the average value.

The protocol (Fuzzy) was compared with Flooding, Weighted *p*-persistence (Wisitpongphan & Tonguz (2007)), MPR Broadcast (Qayyum et al. (2002)) and EMPR Broadcast (Wu et al. (2010)). We did not use retransmission in all these protocols.

4.5.1 Number of broadcasts

Fig. 10 shows the number of broadcasts per data packet for various number of nodes. Flooding generates too many redundant broadcasts in a high density network. As a result, many packets are lost due to packet collisions.

Since the Weighted *p*-persistence uses a probabilistic broadcast method to reduce the redundant rebroadcast, the Weighted *p*-persistence performs better than the flooding. However, the number of broadcasts also increases linearly with the increase of node density. Therefore, redundant rebroadcasts cannot be eliminated entirely. In the MPR Broadcast, EMPR Broadcast and the Fuzzy protocol, only the nodes which have been selected as relay nodes, rebroadcast the packets. Therefore, the redundant broadcast can be reduced efficiently.

4.5.2 Packet dissemination ratio

Fig. 11 shows packet dissemination ratio for various number of nodes. In flooding, as the number of nodes increases, the dissemination ratio decreases. This is because many nodes try

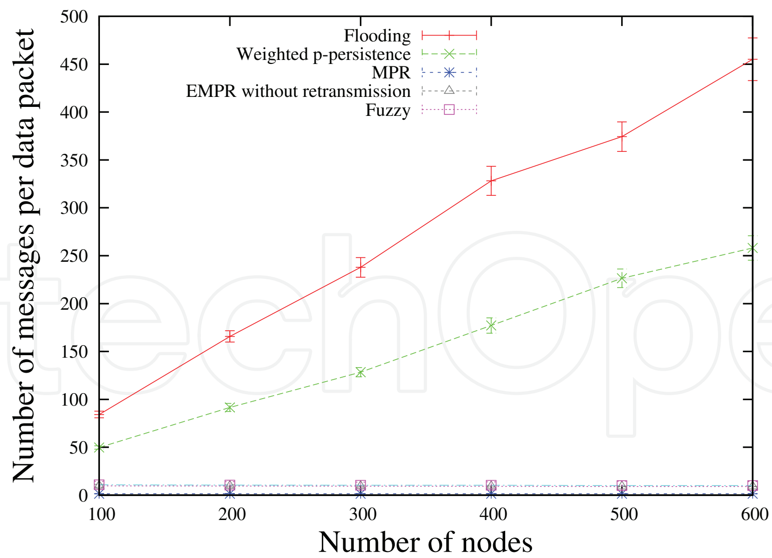

Fig. 10. Number of broadcasts per data packet for various number of nodes.

to broadcast at the same time and this introduces collisions and a drop in packet dissemination ratio.

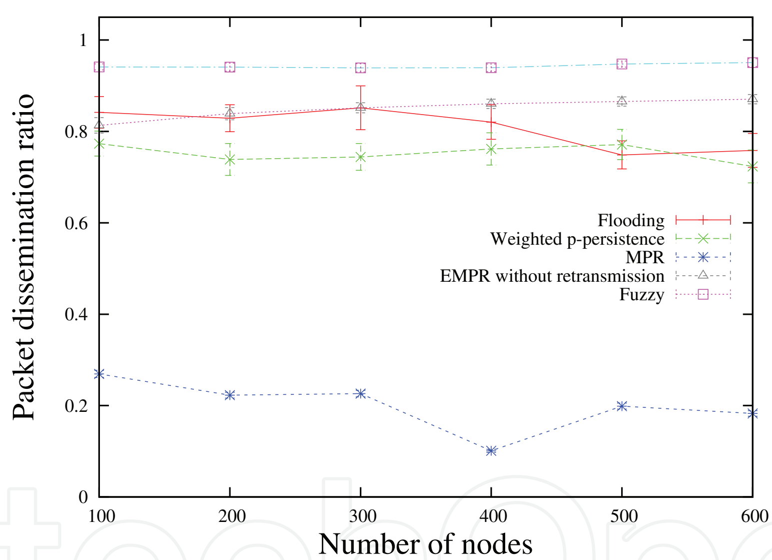

Fig. 11. Packet dissemination ratio for various number of nodes.

The Weighted p-persistence scheme works better than the flooding by reducing the number of broadcasts. However, since a probabilistic method is used, the number of broadcasts also increases as the node density increases, leading to a drop in performance. In the MPR Broadcast, although the number of broadcasts can be efficiently reduced, we observe a poor dissemination ratio. This is because a sender node usually selects the farthest node. However, in a fading channel, the furthest node always fails to receive the broadcast packet. In MPR, since the node mobility is not considered in the relay node selection, a packet loss also occurs at the selected relay node due to the vehicle movement. The EMPR Broadcast performs better than the MPR Broadcast because it considers node mobility in the relay node selection. In the EMPR Broadcast, a sender node selects a relay node which has a low relative mobility and large additional coverage. As the number of nodes increases, the choices increase and therefore the performance of the EMPR Broadcast improves slightly.

The Fuzzy protocol evaluates relay fitness values of relay nodes considering inter-vehicle distance, node mobility and received signal strength. We use Fig. 12 to show the distribution of relay fitness values for various distances and relative velocities. In here, the received signal power on a certain distance is calculated by averaging received signal powers of 10,000 packets in the same distance.

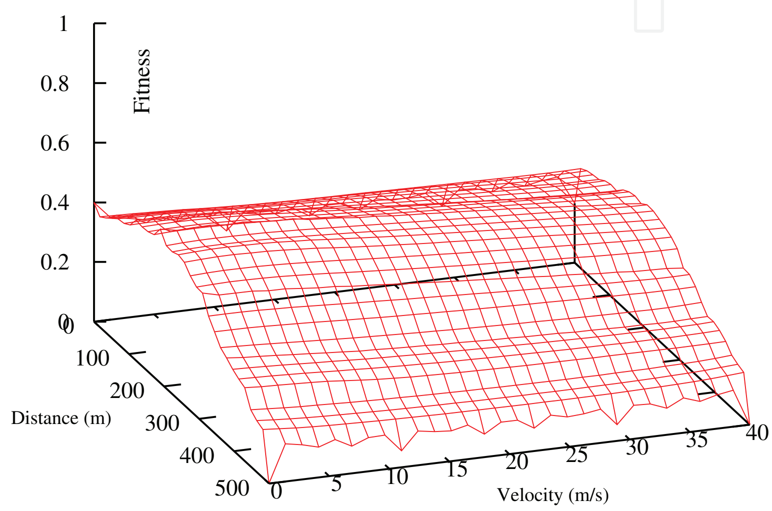

Fig. 12. Relay fitness for various distances and relative velocities.

By jointly considering inter-vehicle distance, node mobility and signal strength, the Fuzzy protocol can deal with node mobility and fading while providing large progress on the dissemination direction. As a result, the Fuzzy protocol provides better packet dissemination ratio (above 94%) than other protocols. The very small number of packet losses are because of the packet collisions. It is possible to get a higher packet reception ratio if we use a retransmission mechanism. However, this is beyond the scope of this work.

4.5.3 End-to-end delay

Fig. 13 shows end-to-end delay for various number of nodes. In the end-to-end delay calculation, we only count the successfully delivered packets. In Flooding, as the node density increases, the delay increases drastically. This is because of the increase of MAC layer contention time with the increase of the number of rebroadcasts. Another reason is the effect of packet losses. When the node density is high, the redundant broadcasts introduce many collisions and consequently the nodes that provide larger progress on distance lose the data packets. As a result, the packets are delayed because they are delivered through sub-optimal paths (longer paths).

In Weighted p-persistence, the end-to-end delay also increases with the increase of the node density because Weighted p-persistence cannot eliminate redundant broadcasts completely.

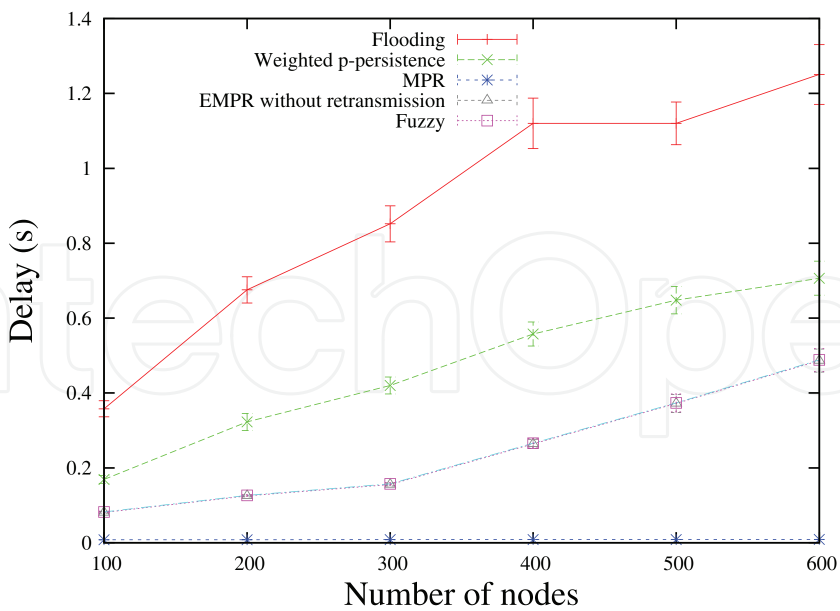

Fig. 13. End-to-end delay for various number of nodes.

MPR shows the lowest delay. This is because MPR chooses the farthest node as a relay node. The low delay of MPR is also because many data messages are lost at the relay node.

EMPR Broadcast and the Fuzzy protocol show comparable delays. Although the selected relay nodes are usually not the farthest possible nodes, the Fuzzy protocol shows lower end-to-end delays. This is because the Fuzzy protocol reduces the contention time at each node by reducing the number of rebroadcasts. The Fuzzy protocol shows an increase of the end-to-end delay with the increase of the number of nodes. This is because with the increase of node density, the number of hello messages increases, resulting in a slight increase of MAC layer contention time at each node. However, this is acceptable because the Fuzzy protocol does show a low delay even when the network density is high.

5. Conclusions

Efficient and reliable relay node selection is important for providing multi-hop broadcast services in vehicular ad hoc networks. Due to the network dynamics of vehicular ad hoc networks, the optimal mathematical model of the relay node selection problem is difficult to derive. As a solution, in this chapter, we presented a fuzzy logic protocol to enhance the multi-hop broadcast in vehicular ad hoc networks. By employing the fuzzy logic into the relay node selection, the protocol considers the inter-vehicle distance, node mobility and signal strength jointly. As a result, a high level of reliability and efficiency are provided. We used computer simulations to evaluate the protocol's performance. The simulation results confirmed that the Fuzzy protocol offers a significant performance advantage over existing alternatives by selecting better relay nodes. The fuzzy logic based approach is easy to implement and can be configured to any scenario by tuning the fuzzy membership parameters.

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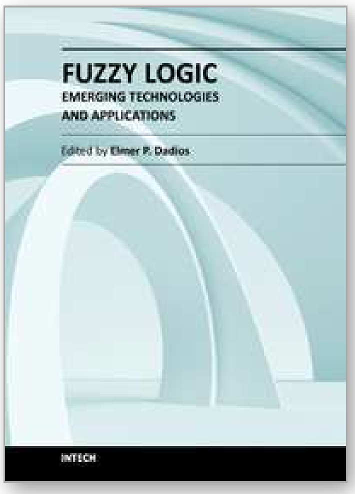

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The capability of Fuzzy Logic in the development of emerging technologies is introduced in this book. The book consists of sixteen chapters showing various applications in the field of Bioinformatics, Health, Security, Communications, Transportations, Financial Management, Energy and Environment Systems. This book is a major reference source for all those concerned with applied intelligent systems. The intended readers are researchers, engineers, medical practitioners, and graduate students interested in fuzzy logic systems.