Fuzzy metric approach for route lifetime determination in wireless ad hoc networks

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Abstract: In wireless ad hoc networks, Ad-hoc On-Demand Distance Vector (AODV) routing protocol uses static value for 'Active-Route-Timeout' (ART) which indicates the lifetime of an active route in the routing table. As accurate and dynamic ART is more suitable than static one, the fuzzy logic system is used here to obtain adaptive ART (fuzzy ART) values. Considering various parameters on fuzzy ART, three design methods are proposed, namely: *fuzzy-SKP*, *fuzzy-Power* and *fuzzy-Comb*. Analysis shows that the proposed methods are able to optimise ART quite efficiently and superior to the conventional method with respect to routing overhead and average end-to-end delay.

Keywords: ad hoc networks; AODV; adaptive route timeout; fuzzy route lifetime.

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1 Introduction

Mobile multi-hop wireless networks, called Ad hoc networks, are networks without infrastructure such as access points or base stations. A node communicates directly with the other nodes within adequate radio propagation and indirectly through multi-hop routing with all others. To allow such on-the-fly formation of networks, numerous routing protocols have been developed.

The route lifetime value is one of the most important parameters for the design of an on-demand ad hoc routing protocol. This parameter determines the duration of an active path/route in the routing table to transmit the packets reliably. This factor is to ensure that the routing table does not attempt to discover a new route and/or delete an existing active route within its lifetime. Therefore, too long a route lifetime may lead to retardation in updating the routing table even though some paths are broken. This results large routing delay and control overhead from attempts to transmit across paths that do not exist. On the other hand: too short a route lifetime may remove some active paths from the routing table. This leads the routing protocol to run the discovery process for those paths again, resulting in large routing delay and traffic overhead due to the new path search. In essence, this means that the protocol designer has to choose the value of route lifetime carefully to represent the real availability of source-destination paths.

The AODV routing protocol is designed for ad hoc mobile networks (Perkins and Royer, 1999, 2001; Perkins, 1997). It allows users to find and maintain routes for other users in the network, whenever needed (on-demand). Since the production of this protocol (Perkins, 1997), static route lifetime values have been used, called ART which indicate the time that the route stays active in the routing table. However, unpredictability and the randomness of node movement make the adaptive determination of route lifetime value better than a static approach. Due to the complexity of this determination, very few researchers attempted to use adaptive route lifetime values. Advanced mathematical tools are used to predict the adaptive route lifetimes, which are very complicated and difficult to understand. These mathematical models result in non-linearity and some degree of errors for estimate nodes mobility.

In this study, an adaptive route lifetime determination through a fuzzy logic system is proposed. Fuzzy logic is chosen due to the uncertainty associated with node mobility estimation and drawbacks of mathematical models. Definition of fuzzy sets (Membership Functions (MFs)) and a set of rules (rule-base) have been proposed to design the new method, called *fuzzy ART*. This new method is evaluated with the AODV routing protocol; we believe that it can be deployed by other ad hoc routing protocols as well.

The rest of this paper is organised as follows. Section 2 summarises related work on optimum route lifetime, followed by the implementation of AODV, using the fuzzy ART method, performance analyses of the proposed method, and finally the conclusion.

2 Related work

In designing on-demand ad hoc routing protocols, four values are used for route lifetime. These are:

- Route lifetime is equal to 0. This means the route is founded when a packet is ready to be transmitted, and kept active during transmission, and deleted at the end of transmission. An example of such a protocol is Associatively Based Routing (ABR) (Toh, 1997). ABR measures the lifetime of a link using 'Hello' messages which are periodically broadcast.
- Route lifetime is equal to infinity. This means that from the time the route is discovered, it is kept active until a broken link is discovered. Examples of such protocols are Dynamic Source Routing (DSR) (Johnson and Maltz, 1996) and Temporally Ordered Routing Algorithm (TORA) (Park and Corson, 2000).
- Route lifetime is equal to a predetermined static value. This means that from the time the route is discovered, it is kept active up to predetermined amount of time. An example of such protocols is AODV (Perkins, 1997). In this protocol, ART is set to 3 s.
- Route lifetime is equal to an adaptive value. This category is subdivided to two subcategories:
  - *Restricted adaptive lifetime.* Paul et al. (1999) introduce a parameter – *affinity* – which characterises the strength and stability of a relationship between two nodes. The path with minimum affinity will be used to transmit data between those two nodes. This path will be saved in the routing table as long as the affinity is greater than a certain threshold.
  - *Un-restricted adaptive lifetime.* The route lifetime is adaptively calculated according to the network situation and kept active as long as the route exists. Examples of such protocols are those proposed by Liang and Haas (2003), Agarwal et al. (2000) and Tseng et al. (2003).

Protocols using the adaptive route lifetime method found interesting results in minimising routing delay and traffic overhead. Researchers who designed these protocols used advanced mathematical tools to determine the values of adaptive route lifetime. In this paper we attempt to simplify these protocols by using the fuzzy logic system.

Some studies estimated models to find a route with longer lifetime. These studies showed that if any one can find optimal routes in the ad hoc network, the average route's lifetime would be longer and this will reduce route maintenance and rerouting overheads. Lim et al. (2002) tried to achieve this goal by using an enhanced link stability estimation model while Cheng and Heinzelman (2004) used a link/route lifetime distribution algorithm. Kumar et al. (2005) proposed that this optimisation goal is composed of three sub-optimisation problems. These sub-problems consist of finding the number of hops, the distances between the intermediate nodes and the intermediate node speeds. The authors considered the problem of characterising the solution of the third sub-problem, assuming that the objective is to find the speeds of the intermediate nodes that achieve maximum route lifetime. Although the benefit of these studies is to find protocols with longer route lifetimes, these protocols suffer from longer time overhead in route discoveries and maintenance functions. This drawback is clear with ad hoc networks consisting of medium and fast speed nodes.

Other studies approach a deeper understanding of the effect of mobility on routes lifetime. Turgut et al. (2001) claim that the lifetime of a particular route is dependent on the speed and direction of movement of all the nodes involved in the route. They argue that if the movement pattern of the nodes is absolutely deterministic then the lifetime of a route can be determined exactly. Sadagopan et al. (2003) examined how the statistics of routes lifetime, including Probability Density Functions (PDFs), vary with the parameters such as the mobility model, relative speed, number of hops, and radio transmission range. Similar work done by Yu et al. (2003) using relative speed only. Gerharz et al. (2003) analysed the stability of paths in a mobile ad hoc environment according to a variety of strategies and under a variety of different mobility patterns.

3 AODV with fuzzy ART

In this section, the concept and rules for fuzzy ART that will be used with AODV are introduced and the method to design its MFs is presented.

3.1 Effect of path length on ART

In mobile ad hoc networks, node mobility causes paths between nodes to break frequently. Although using more hops may reduce the required transmission power to communicate between end nodes, the increasing number of hops also introduces greater risk of route breakage. When the number of hops between the source and destination (*HopCount*) is high, the probability that the path will break because of node movement is also high. The probability of a path break p_b can be calculated as shown Murthy and Manoj (2004):

$$p_b = 1 - (1 - p_l)k \quad (1)$$

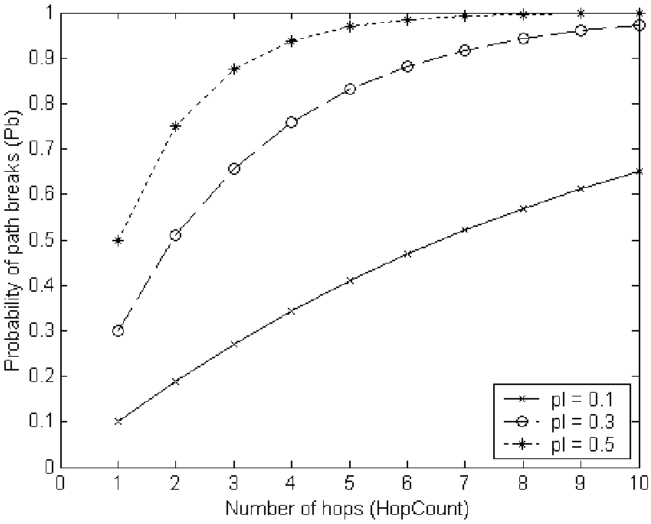
where p_l is the probability of a link break and k is a path length. Figure 1 shows p_b vs. *HopCount* when p_l is equal to 0.1, 0.3 and 0.5. It is clear that the probability of a path break increases as the path length increases, terminating the lifetime of the routes containing those paths (the ART time). Based on previous studies, we can state that when *HopCount* is high, the route lifetime must be low, and vice versa. Consequently the following rules are proposed:

R1: If *HopCount* is high then ART must be low

R2: If *HopCount* is medium then ART must be medium

R3: If *HopCount* is low then ART must be high.

Figure 1 Probability of path breaks vs. *HopCount*



3.2 Effect of node mobility on ART

Ad hoc networks experience dynamic changes in network topology because of the unrestricted mobility of the nodes in the network. If the end nodes (source and destination) move frequently, then it is highly probable that their path will break. The node movement can be measured by the number of sent control packets (*SentCtrlPkt*) between two sampling intervals. *SentCtrlPkt* is any message of the following type: RREQ, RREP, RERR and RREP_ACK. The description of these messages is shown in Table 1. A high number of *SentCtrlPkt* transmissions occur either due to the movement of the intermediate nodes in the path or to the movement of end nodes results in a high probability of losing some of the current links in the path and creating new ones. In general, a rule can be defined: when *SentCtrlPkt* is high, the route lifetime must be low or vice versa. Consequently the following rules are proposed:

R4: If *SentCtrlPkt* is high then ART must be low

R5: If *SentCtrlPkt* is medium then ART must be medium

R6: If *SentCtrlPkt* is low then ART must be high.

Table 1 Messages used by AODV

Message	*Description*
RREQ	A Route Request message
RREP	A Route Reply message
RERR	A Route Error containing a list of the invalid destinations
RREP_ACK	A RREP acknowledgment message

3.3 Effect of node transmission power on ART

The route's lifetime used by the nodes of an ad hoc network is highly sensitive to the transmission power of those nodes. Transmission power (*TrPower*) is the strength with which the signal is transmitted.

In our system, signal power degradation is modelled by the *free space propagation model* (Rappaport, 1996) which states that the received signal strength is:

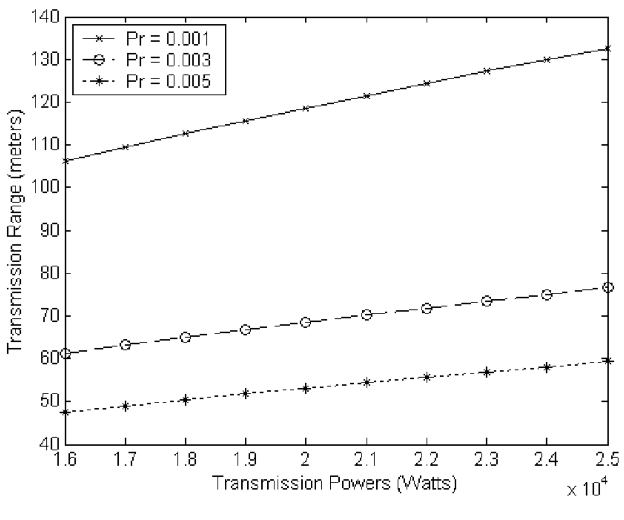
$$P_r(d) = \frac{P_t G_t G_r \lambda^2}{(4\pi)^2 d^2 L} \quad (2)$$

where P_r and P_t are the receive and transmit powers (in Watts), G_t and G_r are the transmit and receive antenna gains, d is the transmitter-receiver separation distance, L is a system loss factor ($L = 1$ in our simulations which indicates no loss in the system hardware), and λ is the carrier wavelength (in metres) which is related to the carrier frequency by:

$$\lambda = \frac{c}{f_c} \quad (3)$$

where f_c is the carrier frequency (in Hertz) and c is the speed of light (3×10^8 m/s). Assuming a unity gain antenna with a 900 MHz carrier frequency, Figure 2 shows the relation between the transmission range and the transmission power of a node for different values of the receiver power.

Figure 2 Transmission range vs. transmission power



Increased transmission power means larger transmission range. If the transmission power of a node is too low, then its signal will reach a few neighbours only and its links with those neighbours may be very weak and easy to break. High transmission power of a node will lead to high average number of its neighbours and hence increase the lifetime of its routes. Consequently the following rules are proposed:

R7: If *TrPower* is high then ART must be high

R8: If *TrPower* is medium then ART must be medium

R9: If *TrPower* is low then ART must be low.

3.4 The rule-base for fuzzy ART

To compare the different parameters that affect ART, we have proposed three methods to design the fuzzy ART:

- *Fuzzy-SKP.* In this method the effect of path length and node mobility are considered. To implement this method, the first six previous rules (R1–R6) can be combined with one 2-dimensional rule-base for controlling the ART adaptively as presented in Table 2.
- *Fuzzy-Power.* In this method the effects of path length (rules R1–R3) and transmission power (rules R7–R9) are combined to design a rule-base shown in Table 3.
- *Fuzzy-Comb.* In this method, the previous two methods are combined. So, ART is calculated by taking the average of ARTs produced by fuzzy-SKP and fuzzy-Power methods.

Table 2 Rule-base for fuzzy-SKP

HopCount	*SentCtrlPkt*		
	Low	*Medium*	*High*
Low	High	High	Medium
Medium	High	Medium	Low
High	Medium	Low	Low

Table 3 Rule-base for fuzzy-Power

HopCount	*TrPower*		
	Low	*Medium*	*High*
Low	Medium	High	High
Medium	Low	Medium	High
High	Low	Low	Medium

3.5 Membership Functions (MFs) for the fuzzy variables

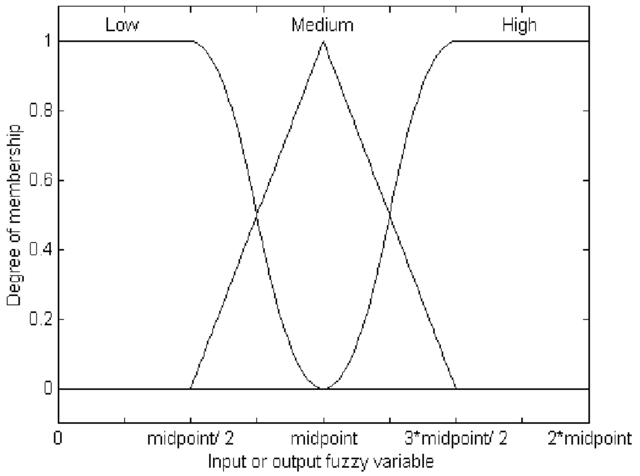
After having defined the fuzzy linguistic 'if-then' rules the MFs corresponding to each element in the linguistic set (*HopCount*, *SentCtrlPkt*, *TrPower*, and *ART*) must be defined. For example, if the *HopCount* equals 4, conventionally, we may say that the *HopCount* is either 'low' or 'medium' but not both. In fuzzy logic, however, the concept of MFs allows us to say the *HopCount* is 'low' with 20% membership degree and it is 'medium' with 80% membership degree.

We used the MFs shown in Figure 3 because the parametric, functional descriptions of these MFs are most economic. In these MFs, the designer needs only to define one parameters; *midpoint*. These MFs contain mainly the *triangular* shaped MF. It has been proven that *triangular* MFs can approximate any other MF (Pedrycz, 1994). This function is specified by three parameters (a, b, c) as follows:

$$\text{triangle}(x;a,b,c)=\begin{cases}(x-a)/(b-a) & \text{for } a\le x\le b\\(c-x)/(c-b) & \text{for } b\le x\le c\\0 & \text{elsewhere}\end{cases} \quad (4)$$

where a = *midpoint*/2, b = *midpoint*, c = 3 × *midpoint*/2 and x is the input to the fuzzy system. The remaining MFs are as follows: Z-shaped membership to represent the whole set of low values and S-shaped membership to represent the whole set of high values.

Figure 3 Membership functions used in fuzzy AODV



Midpoint is the value of the fuzzy variable, which can be chosen from the real network, simulation and analysis or from the default values of protocol specification as follows.

Tseng et al. (2003) compared route breakage probability distribution obtained from random simulation and analysis on route length equal to 3 links, 6 links, 9 links and 12 links. The results showed that the practical sizes of ad hoc networks ranged around five nodes. Hence, for *HopCount* MF, *midpoint* should be equivalent to five nodes.

Midpoint of *SentCtrlPkt* MF is a parameter that indicates the node connectivity. Every node can send four kinds of *SentCtrlPkt* during a second (Table 1). The same message cannot be sent in the same second. Since the default route lifetime is 3s, every node can send a maximum of 12 messages of *SentCtrlPkt* during the same path. Hence, if that node is connected to all nodes in the network, then the number of *SentCtrlPkt* that the nodes can send during the default route lifetime is: number of nodes × 12. Therefore, the *midpoint* of *SentCtrlPkt* MF can be chosen to be:

midpoint = number of nodes × 12.

We do not claim the value for *midpoint* is optimal, or even close to optimal, but it seems to work well in a wide range of scenarios, and we are working on an adaptive algorithm to generate this value.

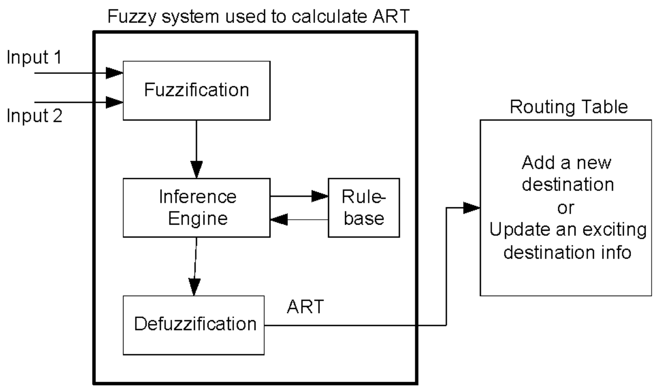
Normally the transmission power of a node can be read from the properties of the network adapter. So, it is easy to expect the minimum and the maximum transmission power for the nodes sharing the network. Hence, *midpoint* for this variable is the average of its ranges. For example, if the transmission powers of a node are between 8 mW and 14 mW then *midpoint* for its *TrPower* MF is 11 mW.

AODV protocol specification (Perkins, 1997) states that the static value of *ART* is 3 s. Hence, for the *ART* MF, *midpoint* should be equivalent to 3 s.

3.6 Fuzzification, inference and defuzzification

The elementary basic diagram of the fuzzy system is presented in Figure 4. Fuzzification is a process where crisp input values are transformed into membership values of the fuzzy sets (as described in the previous section). After the process of fuzzification, the inference engine calculates the fuzzy output using fuzzy rules described in Table 2 (fuzzy-SKP method) or Table 3 (fuzzy-Power method). Defuzzification is a mathematical process used to convert the fuzzy output to a crisp value. This crisp output is the ART value.

Figure 4 Block-diagram for the basic elements of the fuzzy system



The fuzzy logic system has been simulated using C++ programming language. There are a variety of choices in the fuzzy inference engine and the defuzzification method. Based on these choices, a number of different fuzzy systems can be constructed. In this study, we choose the most commonly used fuzzy system (Yager and Filev, 1994).

Formally, we can represent the rule-base (Table 2) of the fuzzy-SKP method in the following format:

IF *HopCount* is A_{i1} AND *SentCtrlPkt* is A_{i2}
THEN *ART* is B_i (5)

where A_{i1}, A_{i2}, and B_i are the linguistic labels *Low*, *Medium*, and *Large* of the *i*th rule.

Mamdani method was used as the fuzzy inference engine, where the Min (∧) operator was chosen as AND connective between the antecedents of the rules as follows:

$$\tau_i = A_{i1}(x_1) \wedge A_{i2}(x_2) \quad (6)$$

where τ_i is called the *degree of firing* of the *i*th rule with respect to the input values $HopCount = x_1$ and $SentCtrlPkt = x_2$. The next step is the determination of the individual rule output F_i (fuzzy set) which is obtained by:

$$F_i(y) = \tau_i \wedge B_i(y). \quad (7)$$

The third step is the aggregation of the rule outputs to obtain the overall system output F (fuzzy set), where Max ($\vee$) operator was chosen as OR connective between the individual rules:

$$F(y) = \vee_i F_i(y) = \vee_i (\tau_i \wedge B_i(y)). \tag{8}$$

For use in the ad hoc networks environment, a fourth step must be added. We need a crisp single value for ART. This process is called *defuzzification*. Center Of Area (COA) was chosen as the defuzzification method given in the following:

$$ART = \frac{\sum_{j=1}^{m} F(y_j) \times y}{\sum_{j=1}^{m} F(y_j)} \tag{9}$$

where y_j is a sampling point in a output F discrete universe, and $F(y_j)$ is its membership degree in the MF.

3.7 Compatibility between static and fuzzy ART methods

Proposed fuzzy-ART methods are compatible with the static-ART method in the sense that a node that uses fuzzy-ART (an ‘intelligent’ node) may communicate with a node that uses static-ART (standard node), since fuzzy-ART does not require any change in the *SentCtrlPkt* messages format or the routing table fields.

4 Performance analysis of the proposed fuzzy ART

4.1 Simulation environment

Simulation of the proposed AODV design was done using *OMNeT++* Version 2.3 with *Ad Hoc simulator* 1.0 (available at: http://www.omnetpp.org/). *OMNeT++* is a powerful object-oriented modular discrete event simulator tool. Each mobile host is a compound module which encapsulates the following simple modules: an application layer, a routing layer, a MAC layer, a physical layer, and a mobility layer.

- *Application layer.* This module produces the data traffic that triggers all the routing operations.
  In all scenarios, five nodes are enabled to transmit. The traffic is modelled by generating a packet burst of 64 packets sent to a randomly chosen destination that stays the same for all the burst length. The rate of each burst sending packets is three packets/s. The time elapsed between two application bursts is normally distributed in [0.1, 3] s. The packet size is 512 bytes.
- *Routing layer.* The routing model is the heart of the simulator. This model depicts the AODV routing protocol, all of its functions, parameters and their implementation (Perkins, 1997).
- *MAC layer.* The simple implementation for this layer has been used. The outgoing messages are allowed to pass through. The incoming one, instead, is delivered to the higher levels with an *MM1 queue* policy. When an in-coming message arrives, the module checks a flag that advises if the higher level is busy. If so, the message will be saved in the buffer or, if the buffer is full, it will be dropped. When the higher level is not busy, the MAC module picks the first message from the buffer and sends it upward.
- *Physical layer.* It cares about the on-fly creation of links that allow the exchange of messages among the nodes. Every time a node moves from its position an interdistance check on each node is performed.
  If a node gets close enough (depending on the TrPower of the moving nodes) to a new neighbour, a link is created between the two nodes with the following properties: channel bandwidth is 11 Mb/s (IEEE 802.11a) and delay is 10 µs. Each node has a defined transmission range chosen from a uniformly distributed number between [90, 120] m.
- *Mobility layer.* The *random waypoint* model was adopted for the mobility layer. It is one of the most used mobility patterns in the ad hoc network simulations. This is because of its simplicity and its quite realistic mobility pattern. In this mobility model, a node randomly selects a destination. On reaching the destination, another random destination is targeted after 3 s *pause time*. The speed of movement of individual nodes ranges between [0, 10] m/s. The direction and magnitude of movement was chosen from a uniformly distributed random number.

Two different network sizes are modelled: 700 × 700 m map size with 25 nodes and 800 × 800 m map size, with 35 nodes. Each simulation run takes 300 simulated seconds. Multiple runs were conducted for each scenario and the collected data were averaged over those runs.

4.2 Performance metrics

Three metrics were used for measuring performance:

- *Routing overhead*:

$$\text{Overhead} = \frac{\sum_{i=1}^{n} \text{Number of } \textit{SentCtrlPkt} \text{ by source}}{\sum_{i=1}^{n} \text{Number of received data by destination}} \tag{10}$$

  where n is number of nodes in the network. This metric can be employed to estimate how many transmitted control packets are used for one successful data packet delivery, to determine the efficiency and scalability of the protocol.

- *Average end-to-end delay*: Average packet delivery time from a source to a destination. First, for each source-destination pair, average delay for packet delivery is computed. Then the whole average delay is computed from each paired average delay. End-to-end delay includes the delay in the send buffer, the delay in the interface queue, the bandwidth contention delay at the MAC, and the propagation delay.
- *Invalid route ratio*:

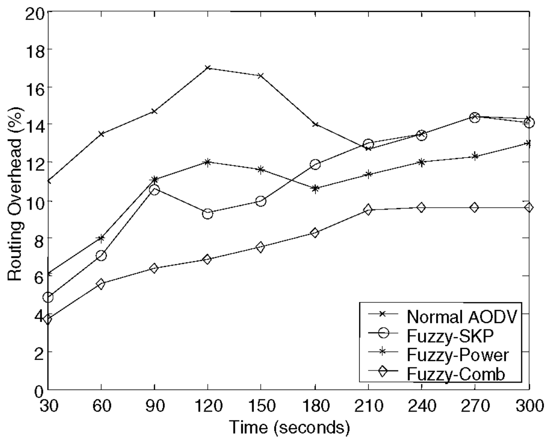
$$\text{Invalid Route Ratio} = \frac{\sum \text{Number of invalid routes}}{\sum \text{Number of valid routes}} \quad (11)$$

Each time a route is used to forward a data packet, it is considered as a valid route. If that route is unknown or expired, it is considered as an invalid route.

4.3 Simulation results and evaluations

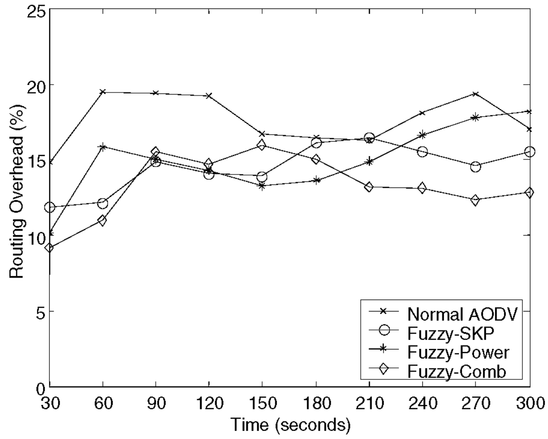
Comparison between routing overhead of normal AODV and the proposed fuzzy design methods are shown in Figure 5. Using normal AODV as a base system, the results show that the proposed fuzzy methods decrease routing overhead with average 25.2% than the normal AODV. This decrement in the routing overhead is due to the decrease in the number of *SentCtrlPkt* that were used to maintain and recover the connection, as well as minimum data loss through broken paths, hence increased number of received data by destination. Fuzzy AODV methods have less route recoveries and, hence, less *SentCtrlPkt*. Therefore, it improves the efficiency and scalability of the protocol. It is interesting to note that the fuzzy-Comb method has shown significant enhancement over the normal AODV (and to a lesser extent non-combined fuzzy methods). This is due to combining the three parameters (path length, node mobility, and *TrPower*) to choose a reliable value for ART. In this method, many paths are given a very short ART due to the inability to maintain a route. Hence, with fewer paths being maintained, fewer route recoveries are necessary.

Figure 5 Routing overhead comparison: (a) 25 nodes; (b) 35 nodes and (c) percentage of improvement than the normal AODV

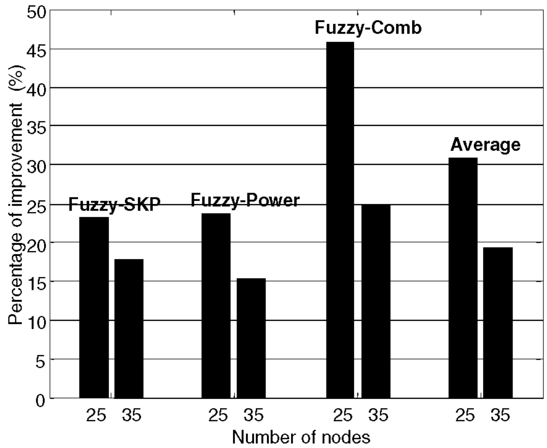


(a)

Figure 5 Routing overhead comparison: (a) 25 nodes; (b) 35 nodes and (c) percentage of improvement than the normal AODV (continued)



(b)



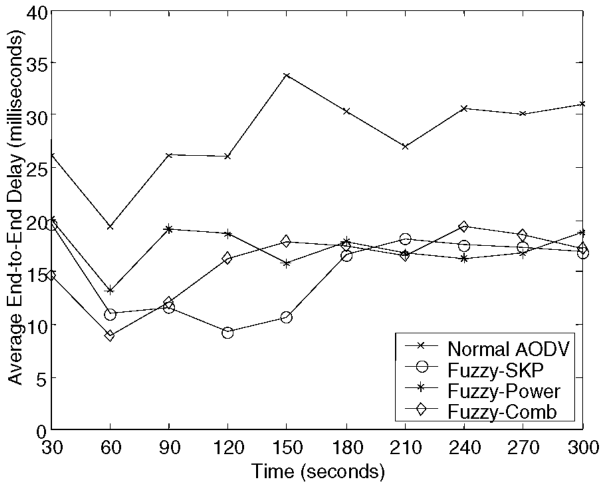
(c)

Figure 6 indicates that the proposed fuzzy AODV methods have lower average end-to-end delay compared to normal AODV with average 41.2%. The normal AODV needs more routing delay to recover from broken paths and discover new ones. To recover a broken path, a RERR message must first be initiated from the intermediate node to inform their end nodes (i.e., source and destination nodes) about the link break. The end nodes delete the corresponding entries from their routing table. The RREQ must then be broadcast from the source to the destination, and a RREP consequently has to be transmitted back to the source. Data packets are buffered at the source node during this process and the duration of their buffering adds to the end-to-end delay. Fuzzy AODV methods, on the other hands, have reliable routes that minimise the need to this recovery process. As expected, the node mobility parameter used by the fuzzy-SKP method had more effect on route reliability than the transmission power parameter used by the fuzzy-Power method.

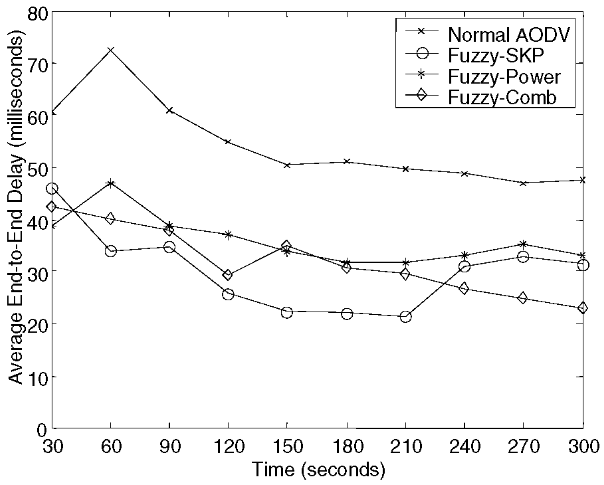
As expected, the average invalid route ratio for fuzzy-ART methods are less than the static method as shown in Figure 7. The percentage of fuzzy-ART methods improvement is about 42.3% and 29.8% compared to 25 and 35 nodes network for fuzzy-SKP method, 29.78%

and 27.1% compared to 25 and 35 nodes network for fuzzy- Power method, whereas it is 43.2% and 34% compared to 25 and 35 nodes network for the fuzzy-Comb method, respectively.

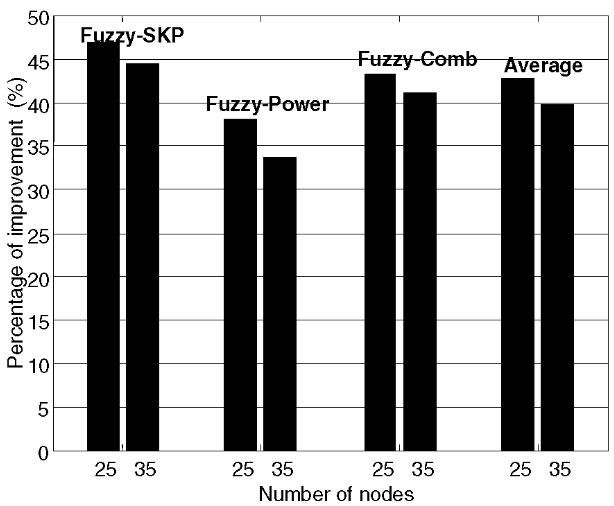
Figure 6 Average end-to-end delay comparison: (a) 25 nodes; (b) 35 nodes and (c) percentage of improvement than the normal AODV



(a)

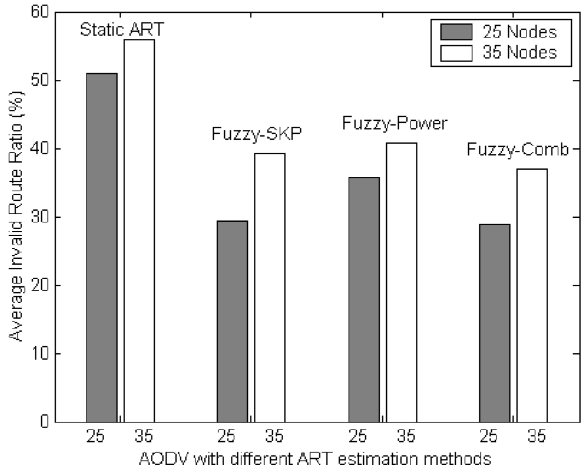


(b)



(c)

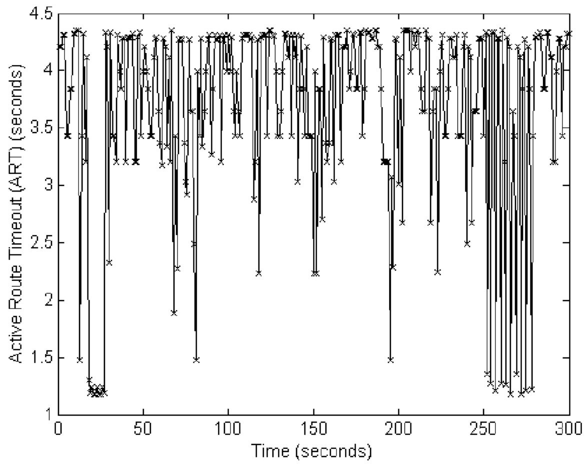
Figure 7 Invalid route ratio comparison



This improvement of the fuzzy methods is a result of choosing the reliable adaptive links status monitoring to update the paths in the routing table. The worse result of static methods is due its specification stating that a route lifetime for a path has to be shifted in the future, each time a Hello message is received using that path. This is a very bad role-played by the AODV as it makes the paths request more frequently than they actually needed. Work toward developing techniques for quickly re-establishing valid routes is likely to be of the highest importance for improving the AODV protocol.

In the normal AODV, ART always take a static value of 3 s. Figure 8 shows the values used by the proposed fuzzy ART for a randomly chosen node in our simulated network. It is shown that the fuzzy ART uses a variety of values between 1 s and 4.5 s. This value of fuzzy ART is used by one node in our 25 nodes simulated scenario. Every node in the network has its own values of ART for every path in the routing table.

Figure 8 Fuzzy ART values used by a node



5 Conclusion and future work

The paper proposes the use of a fuzzy mechanism for generating adaptive values for optimum route lifetimes in the AODV routing protocol. Three approaches utilising the path length, the node mobility, and the transmission power have been used to create a 2-dimensional rule-bases to control the timeout delay adaptively. The performance of the proposed models has been compared with the performance of the original AODV. The performance analysis showed that the proposed fuzzy models have a better routing overhead and average end-to-end delay than the original method. Hence, fuzzy logic AODV has shown more advancement than the original AODV and is expected to perform better in wireless ad hoc networks.

In this study, we chose three parameters that reflected the lifetime of the paths effectively and hence provided good hints about the ART value. In future research study other parameters can be used such as Single to Noise Ratio (SNR), relative speed, mobility model and others.

Overall, the work presented here gave us an insight that the ad hoc routing protocols configuration parameters might be determined more accurately and dynamically by a fuzzy logic system, instead of static values. Therefore, more research studies could focus on using fuzzy logic system to optimise these parameters.

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References

Agarwal, S., Ahuja, A., Singh, J. and Shorey, R. (2000) 'Route-Lifetime Assessment Based Routing (RABR) protocol for mobile ad-hoc networks', *IEEE Int'l Conf. Comm.*, New Orleans, USA, June 18–22, pp.1697–1701.

Cheng, Z. and Heinzelman, W.B. (2004) 'Exploring Long Lifetime Routing (LLR) in ad hoc networks', *Proc. of the 7th ACM Int'l Symposium on Modeling, Analysis and Simulation of Wireless and Mobile Systems*, Italy, October 4–6, pp.203–210.

Gerharz, M., Waal, C., Martini, P. and James, P. (2003) 'Strategies for finding stable paths in mobile wireless ad hoc networks', *Proc. of the 28th IEEE Conf. on Local Computer Networks (LCN)*, Bonn, Germany, October, pp.130–139.

Johnson, D.B. and Maltz, D.A. (1996) 'Dynamic source routing in ad hoc wireless networks', in Imielinski, T. and Korth, H. (Eds.): *Mobile Computing*, Chapter 5, Kluwer Academic Publishers, pp.153–181.

Kumar, D., Kherani, A.A. and Altman, E. (2005) *Route Lifetime based Interactive Routing in Intervehicle Mobile Ad Hoc Networks*, INRIA Research Report No. RR-5691, Sophia-Antipolis, France, September.

Liang, B. and Haas, Z.J. (2003) 'Optimizing route-cache lifetime in ad hoc networks', *Proc. of the 22th IEEE INFOCOM*, San Francisco, CA, April 1–3, pp.281–291.

Lim, G., Shin, K., Lee, S., Yoon, H. and Ma, J.S. (2002) 'Link stability and route lifetime in ad-hoc wireless networks', *Proc. of the Int'l Conf. on Parallel Processing Workshops (ICPPW'02)*, Vancouver, Canada, August 18–21, pp.116–123.

Murthy, C.S. and Manoj, B.S. (2004) *Ad Hoc Wireless Networks: Architectures and Protocols*, Prentice-Hall, New Jersey, pp.457–459.

Park, V. and Corson, M.S. (2000) *MANET Internet Draft*, draft-ietf-manet-tora-spec-03.txt, November.

Paul, K., Bandyopadhyay, S., Mukherjee, A. and Saha, D. (1999) 'Communication-aware mobile hosts in ad-hoc wireless network', *Proc. Int'l Conf. Personal Wireless Comm.*, Jaipur, India, February 17–19, pp.83–87.

Pedrycz, W. (1994) 'Why triangular membership functions?', *Fuzzy Sets Syst*., Vol. 64, pp.21–30.

Perkins, C.E. (1997) *Ad Hoc On Demand Distance Vector (AODV) Routing*, Internet-Draft, 20 November, Available at: http://tools.ietf.org/id/draft-ietf-manet-aodv-00.txt (Work in progress), Last Access Date: 16th April 2007.

Perkins, C.E. and Royer, E.M. (1999) 'Ad-hoc on-demand distance vector routing', *Proc. of the 2nd IEEE workshop on Mobile Computing Systems and Applications*, New Orleans, LA, February, pp.90–100.

Perkins, C.E. and Royer, E.M. (2001) 'The ad-hoc on-demand distance vector protocol', in Perkins, C.E. (Ed.): *Ad Hoc Networking*, Addison-Wesley, Boston, Chapter 6, pp.173–220.

Rappaport, T.S. (1996) *Wireless Communications: Principles and Practice*, Prentice-Hall, Chapter 3, pp.70−74.

Sadagopan, N., Bai, F., Krishnamachari, B. and Helmy, A. (2003) 'PATHS: analysis of PATH duration statistics and their impact on reactive MANET routing protocols', *Proc. of the 4th ACM Int'l Symposium on Mobile Ad-hoc Networking and Computing*, Maryland, USA, June, pp.245–256.

Toh C-K. (1997) *Wireless ATM and Ad Hoc Networks: Protocols and Architectures*, Kluwer Academic Press, Boston.

Tseng, Y., Li, Y. and Chang, Y. (2003) 'On route lifetime in multihop mobile ad hoc networks', *IEEE Trans. on Mobile Computing,*, Vol. 2, No. 4, October, pp.366, 376.

Turgut, D., Das, S.K. and Chatterjee, M. (2001) 'Longevity of routes in mobile ad hoc networks', *Proc. of the IEEE VTC*, Vol. 4, May, pp.2833–2837.

Yager, R.R. and Filev, D.P. (1994) *Essentials of Fuzzy Modeling and Control*, John Wiley & Sons, New York, pp.109–153.

Yu, D., Li, H. and Gruber, I. (2003) 'Path availability in ad-hoc network', *Proc. of the Int'l Conf. on Telecommunications (ICT 2003)*, France, February, pp.383–387.