Adaptive Fuzzy Route Lifetime for Wireless Ad-hoc Networks

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Abstract: *Ad-hoc On-Demand Distance Vector (AODV) routing protocol has been and continues to be a very active and fruitful research protocol since its introduction in the wireless ad-hoc networks. AODV uses a static value for its route lifetime parameter called Active Route Timeout (ART) which states the time that the route can stay active in the routing table. Route lifetime may be more accurately determined dynamically via measurement, instead of using a statically configured value. To accomplish this, the fuzzy logic system was used to obtain adaptive values for ART depending on the situation of the transmitter and intermediate nodes. Analysis shows that the proposed design method is quite efficient and superior to the conventional design method with respect to data packet delivery ratio, 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 with no infrastructure such as access points or base stations A node communicates directly with the other nodes within adequate radio propagation and indirectly through multi-hope routing with all others. To allow such on-the-fly formation of networks, numerous routing protocols have been developed.

Choosing route lifetime value is one of the most important parameters during design of on-demand ad-hoc routing protocols. This parameter determines to what extent the path stays active in the routing table and hence can be chosen to transmit the packets. This is to ensure the routing table does not try to discover a new route or delete an existing route whilst the route lifetime does not expire. So, if too high a route lifetime is chosen, it may lead to retardation in the updating of the routing table even if some paths are broken resulting in large routing delay and control overhead from attempting to transmit across paths that do not exist. On the other hand, if too small a route lifetime is chosen, it will remove some paths from the routing table even if those paths are still active. This will lead to the routing protocol running the discovery process for those paths again, leading to large routing delay and traffic overhead resulting from the new path search. In essence this means that, the protocol designer has to carefully choose the value of route lifetime to represent the real availability of source-destination paths.

Ad-hoc On-Demand Distance Vector (AODV) routing protocol [12, 13, 14] has been designed for use in ad-hoc mobile networks. It allows users to find and maintain routes for other users in the network, whenever such routes are needed. Since the production of AODV by Perkins C. [14], static values have been used f (ART) which state the time that the route stays active or its route lifetime parameters, called Active Route Timeout in the routing table. However, the unpredictability and the randomness of the node movement make the adaptive determination of route lifetime value better than a static approach. Due to the complexity of this determination, few network researchers attempted to use adaptive values for route lifetime parameters. These researchers have been using more and more advanced mathematical tools to predict route lifetime. However, this has resulted in fewer and fewer networks engineers understanding these design methods.

In this paper, we propose to use adaptive route lifetime through a fuzzy logic system. Fuzzy logic was chosen due to the uncertainty associated with node mobility estimation and to the non-linearity and lack of mathematical models capable of estimating this mobility. A fuzzy sets definition (membership functions) and a set of rules (rule-base) have been proposed to design the new method, called *fuzzy ART*. Although this new method is evaluated with the AODV routing protocol, we believe it can be generalized for application on other on-demand routing protocols as well.

The rest of this paper is organized as follows. Section 2 summarizes related work on optimizing route lifetime and using fuzzy logic in routing protocols. Section 3 discusses the implementation of AODV using the fuzzy ART method. Performance analyses of the proposed fuzzy AODV are presented in section 4, and the conclusion is in section 5.

2. Related Work

In this section, we summarized literature on optimizing route lifetime. Existing surveys on using fuzzy logic in routing protocols are also discussed in this section.

2.1. Route Lifetime Optimization

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

1. 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 protocol is ABR [17].
2. Route lifetime is equal to infinity: This means that from the time the route is discovered, it is kept active until the broken link is discovered. Examples of such protocol are DSR [5] and TORA [8].
3. Route lifetime is equal to a predetermined static value: An example of such protocol is AODV [14]. In this protocol, there is a static value named Active Route Timeout (ART) equal to 3 milliseconds which determines the period the route can stay active in the routing table.
4. Route lifetime is equal to an adaptive value: This category is subdivided to two subcategories.
   a. Restricted adaptive lifetime. Paul *et al.* [10] introduces a parameter *affinity* which characterizes 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.
   b. Unrestricted adaptive lifetime. Examples of such protocol are those proposed by Ben *et al.* [6], Agarwal *et al.* [2] and Tseng *et al.* [18].

   Protocols that used the adaptive route lifetime method found interesting results in minimizing 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.

2.2. Using Fuzzy Logic in Routing Protocols

Ghosh *et al.* [4] presented a survey on the use of fuzzy logic in telecommunication networks. Sekercioglu *et al.* [16] and Bonde *et al.* [3] reported a similar survey on the use of fuzzy logic in ATM networks.

Using fuzzy numbers to represent uncertainty in the delay values, Pithani *et al.* [15] have developed fuzzy comparison criteria using this uncertainty in making routing path decisions. Aboelela *et al.* [1] defined a fuzzy cost to reflect the crisp values of the different metrics that possibly can be used in the network links. The fuzzy system is then integrated into a complete routing system. Pasupuleti *et al.* [9] proposed an adaptive routing algorithm in which the link cost is dynamically assigned using a fuzzy system. The traffic in the network is re-routed to nodes which are less congested, or have spare capacity.

A few studies have also been undertaken using fuzzy logic in ad-hoc routing protocols. Wong *et al.* [19] presented a fuzzy-decision-based protocol, developed on Dynamic Source Routing (DSR) routing protocol with the support of QoS parameters.

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 membership functions 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 distance between paths, 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 [7]:

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

Where p_l is the probability of a link break and k is a path length. Figure 1 shows p_b versus *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.

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 experience much movement, 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 packets sent occurs either due to the movement of the intermediate nodes in the path or to the movement of end nodes. So, sending of a high number of these packets results in the high probability of loosing some of the current links in the path and creating new ones, which also terminate the lifetime for that path. In general, a rule can be defined: When *SentCtrlPkt* is high, the route lifetime must be low and vice versa. Consequently the following rules are proposed:

R4: If *SentCtrlPkt* is high then ART must below.
R5: If *SentCtrlPkt* is medium then ART must be medium.
R6: If *SentCtrlPkt* is low then ART must be high.

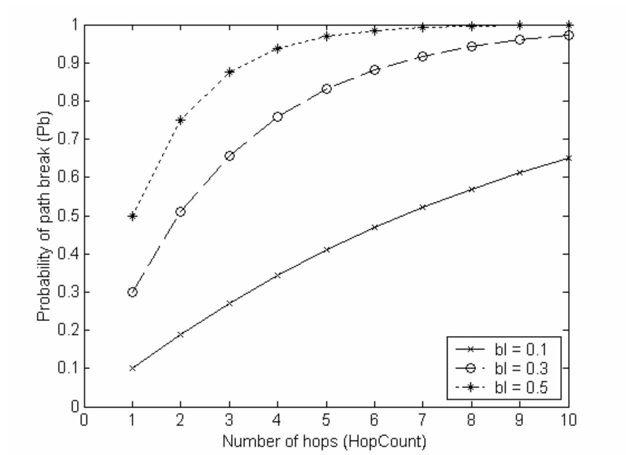


Figure 1. Probability of path breaks versus *HopCount*.

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. Rule Basef or Fuzzy ART

The six previous rules can be combined with one 2-dimensional rule-base for controlling the ART adaptively as represented in Table 2. These 'if-then' rules statements were used to formulate the conditional statements that comprise fuzzy logic. The inputs to 'if-then' rules are the numerical values for the input variables (in this case, *HopCount* and *SentCtrlPkt*) and the output is an entire fuzzy set (in this case, *ART*). This set will later be *defuzzified*, assigning one numerical value to the output.

Table 2. Rule-base for fuzzy ART.

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

3.4. Membership Functions for the Fuzzy Variables

Having defined the fuzzy linguistic rules, the membership functions corresponding to each element in the linguistic set (*HopCount*, *SentCtrlPkt*, and *ART*) must be defined.

We propose to use the membership functions shown in Figure 2 because the parametric, functional descriptions of these membership functions are most economic. In these membership functions, the designer needs only to define two parameters; *midpoint* and *maxpoint*. These membership functions contain mainly the *triangular* shaped membership function. It has been proven that *triangular* membership functions can approximate any other membership function [12]. The remaining membership functions 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.

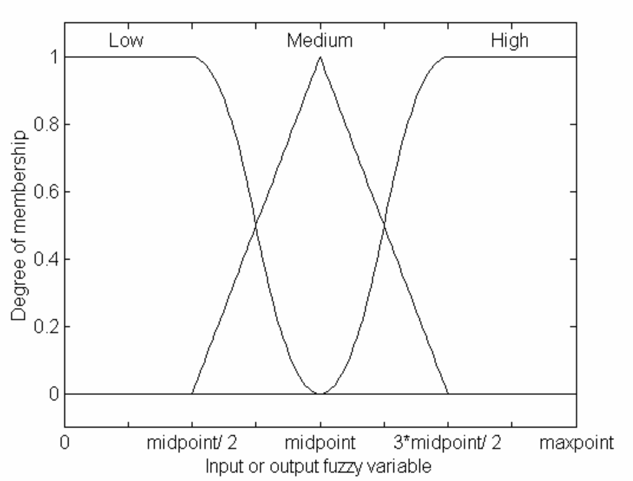


Figure 2. Membership functions used in fuzzy AODV.

Midpoint is the value of the variable, which can be chosen from the real network, simulation and analysis, or from the default values of protocol specification. Tseng *et al.* [18] 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 would range around 5 nodes. Hence, for *HopCount* membership function, *midpoint* should be equivalent to 5 nodes.

The value of *SentCtrlPkt* depends on the number of nodes in the network. So, the *midpoint* can be calculated as:

$$midpoint = \text{number of nodes} \times 10$$

This value has been observed during a run of ad-hoc network simulator (described in the next section) with different sizes of the network. AODV protocol specification [14] states that the static value of *ART* is 3 milliseconds. Hence, for the *ART* membership function, *midpoint* should be equivalent to 3 milliseconds.

Since the values of input variables (*HopCount* and *SentCtrlPkt*) occur during the simulation run, exact knowledge of their values cannot be determined. The range of values *maxpoint* for these variables must be quite large. Hence, *maxpoint* can be defined as follows:

For input variables: *maxpoint* = 3 × *midpoint*.
For output variable: *maxpoint* = 2 × *midpoint*.

The fuzzy system was built using membership functions as shown in Figure 3.

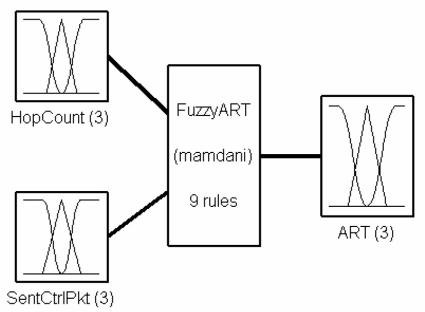


Figure 3. Fuzzy system used to obtain ART.

3.5. Fuzzification, Inference and Defuzzification

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. Defuzzification is a mathematical process used to convert the fuzzy output to a crisp value. This crisp output is the ART value.

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 [21].

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

If *HopCount* is A_{i1} and *SentCtrlPkt* is A_{i2} then *ART* is B_i (2)

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 Min (∧) operator was chosen as AND connective between the antecedents of the rules as follows:

$$\tau_i = A_{i1}(x_1) \wedge A_{i2}(x_2) \tag{3}$$

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 obtained by:

$$F_i(y) = \tau_i \wedge B_i(y) \tag{4}$$

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

$$F(y) = \vee_i F_i(y) = \vee_i (\tau_i \wedge B_i(y)) \tag{5}$$

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:

$$ART = \frac{\sum_{j=1}^{m} F(y_j) \times y_j}{\sum_{j=1}^{m} F(y_j)} \tag{6}$$

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

Table 3. Simulation parameters.

Map and Hosts		Physical Layer	
Map Size	700m x 700m	Channel Bandwidth	11 Mb/s IEEE 802.11a
Number of Hosts	25 or 35	Channel Delay	10 μs
Host Enabled to Transmit	5	Channel Error Probability	1 bit on 10^6
Routing Layer		**Application Layer**	
Control Message Size	64 byte	Enabled Node	5
HELLO Interval	1 s	Message Packet Size	512 byte
Allowed *HELLO* Loss	2	Burst Length	64 Packets
Delete Period	4 s	Send Packet Rate	3/s
RREQ Max Trials	3	Burst Interval	Normally Distributed in [0.1,3]s

4. Performance Analysis of the Proposed Fuzzy ART

4.1. Simulation Environment

For simulating the proposed AODV design method, the *OMNeT++* version 2.3 was used with *Ad Hoc sim* version 1.0 developed by *Nicola Concer* [20].

OMNeT++ is a powerful object-oriented modular discrete event simulator tool. Each mobile host is a compound module which encapsulates the following simple modules: A physical layer, a MAC layer, a routing layer, an application layer, and a mobility layer. Each host has defined transmission power that affects the range where communication is feasible. Signal power degradation is modeled by the *free space propagation model* which states that the received signal strength is inversely proportional to the node distance square. The simulation analysis was performed with the parameters summarized in Table 3. Each simulation run takes 300 simulated seconds.

The *random waypoint* model was adopted for the mobility model. In this mobility model, a node randomly selects a destination. On reaching the destination, another random destination is targeted after 3 seconds pause time.

The pattern and speed of movement of individual nodes range from 0 to 10 units per second. The direction and magnitude of movement is chosen from a uniformly distributed random number. The behavior of the map borders is chosen to be tropical behavior, i. e. makes the node leave the map from one side and re-enter from the opposite side.

4.2. Performance Metrics

Three metrics were used for measuring performance:

- *Data Packet Delivery Ratio*:

$$\text{Delivery Ratio} = \frac{\sum \text{Number of received data by dest.}}{\sum \text{Number of sent data by source}} \quad (7)$$

This metric can measure the delivery reliability and the throughput of the protocol.

- *Routing Overhead*:

$$\text{Overhead} = \frac{\sum \text{Number of SentCtrlPkt by source}}{\sum \text{Number of received data by dest.}} \quad (8)$$

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*:

$$\textit{Invalid Route Ratio} = \frac{\sum_{i=1}^{n} \textit{Number of invalid routes}}{\sum_{i=1}^{n} \textit{Number of valid routes}} \quad (9)$$

Where n is number of nodes in the network. 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 invalid route.

4.3. Simulation Results and Evaluations

Comparison between *data delivery ratios* of normal AODV and the proposed fuzzy design method using 25 nodes network are shown in Figure 4. Using normal AODV as a base system, the results show that the proposed fuzzy AODV increases delivery reliability and the throughput of the protocol about 11 percent over the normal AODV. This increment is due to minimizing the sent data through unreal paths (broken paths), hence increasing the number of received data by destination. This advantage is a result of choosing the adaptive route lifetime to update the paths in the routing table.

The decline in *data delivery ratio* for normal AODV (and to a less extent fuzzy AODV) throughout the simulation period, shown in Figure 4 is due to the use of a simple MAC layer in the simulation that implements a simple channel access policy. This unreliable system is made even worse by the normal AODV specification stating that a route lifetime for a path has to be shifted in the future each time a data message is sent using that path. Given this route lifetime, this is a very bad role played by normal AODV as it makes the paths request for much more time than they actually needed.

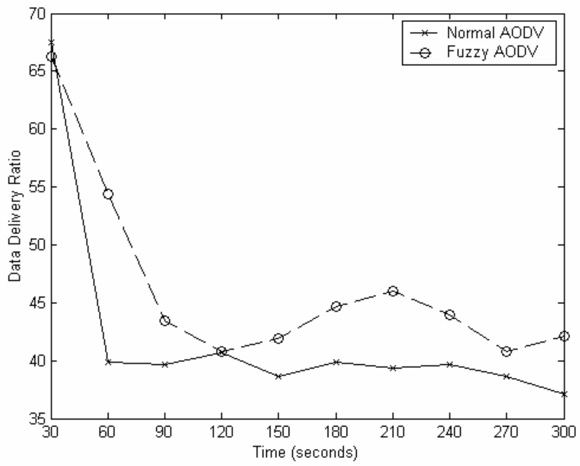
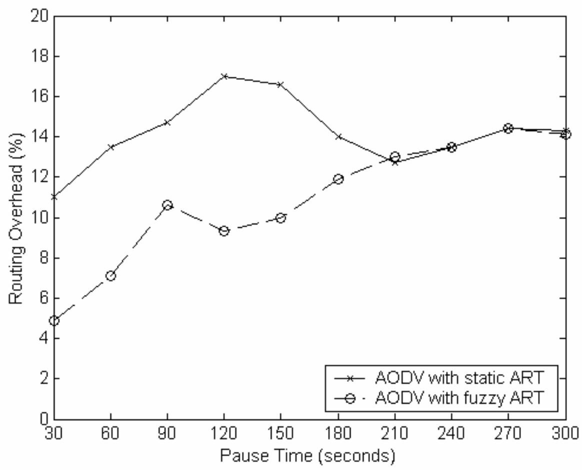


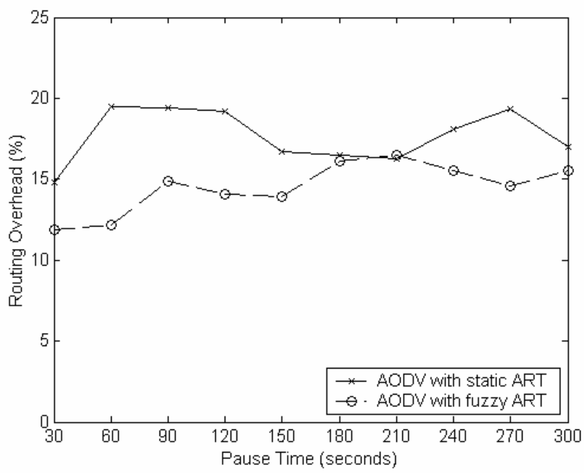
Figure 4. Delivery ratio comparison.

Comparison between routing overhead of normal AODV and the proposed fuzzy design method is shown in Figure 5. Using normal AODV as a base system, the results show that the proposed fuzzy method decreases routing overhead with average 20.6% than the normal AODV, as shown in Figure 7.

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 the number of received data by destination. Fuzzy AODV method has less route recoveries, and hence less SentCtrlPkt. It therefore improves the efficiency and scalability of the protocol.



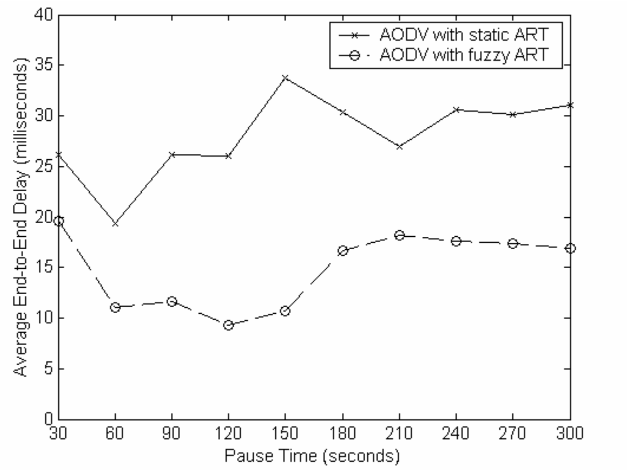
(a) 25 nodes.



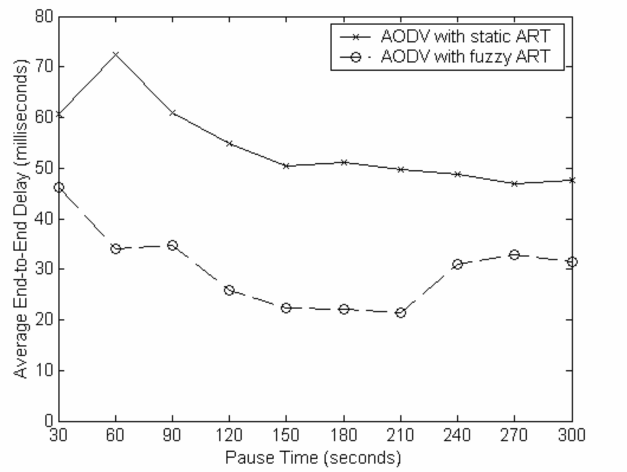
(b) 35 nodes.

Figure 5. Routing overhead comparison.

Figure 6 indicates that the proposed fuzzy AODV method has lower average end-to-end delay compared to normal AODV with average 45.6%, as shown in Figure 7. 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 broadcasted 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 method, on the other hands, has reliable routes that minimize the need to this recovery process.



(a) 25 nodes.



(b) 35 nodes.

Figure 6. Average end-to-end delay comparison.

Figure 8 shows the percentage of invalid routes, using 25 nodes network, for the twoprotocols as follows: Normal AODV 52.9% and fuzzy AODV 29.4%. This decrement for the fuzzy method is a result of choosing the reliable adaptive route lifetime to update the paths in the routing table. The worse result of normal AODV is due its specification stating that a route lifetime for a path has to be shifted in the future each time a data message is sent using that path. This is a very bad role played by the AODV as it makes the paths request for much more time 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.

While in the normal AODV, Active Route Timeout (ART) always take a static value of 3 milliseconds, Figure 9 shows the values used by the proposed *fuzzy ART* for randomly chosen nodes in our simulated network. It is shown that the *fuzzy ART* uses a variety of values of between 1 millisecond and 4.5 milliseconds. This value of *fuzzy ART* is used by one node in our 25–node simulated scenario. Every node in the network will have its own values of ART for every path in the routing table.

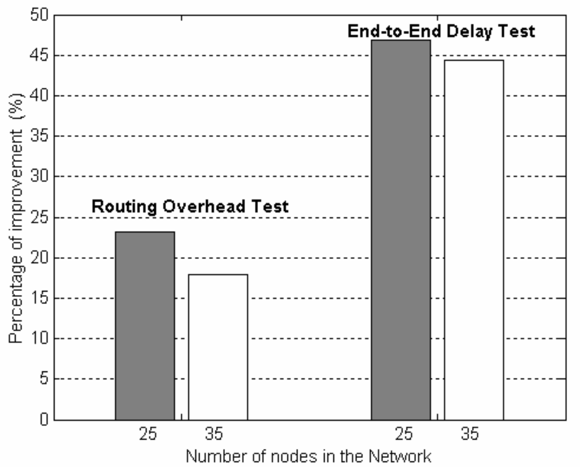


Figure 7. Percentage of the improvement of the proposed fuzzy method than the original method.

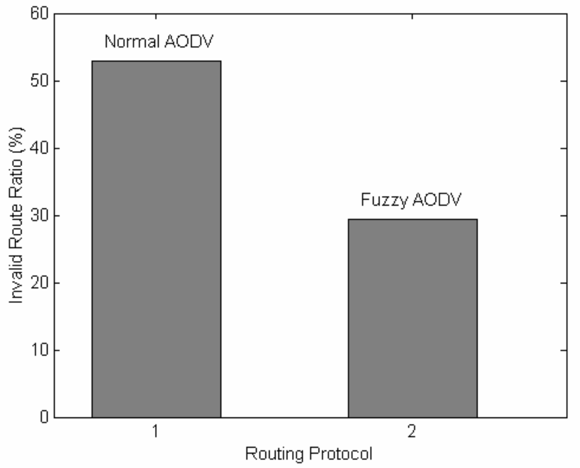


Figure 8. Invalid route ratio comparison.

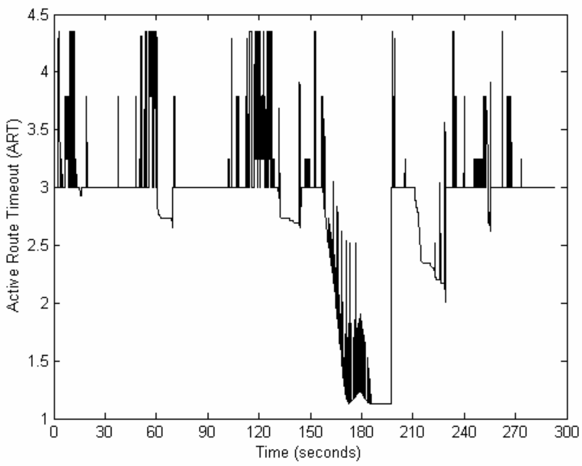


Figure 9. Fuzzy ART values used by a node.

5. Conclusion

The paper proposes the use of a fuzzy mechanism for generating adaptive values for route lifetimes in the AODV routing protocol. The approach utilizes the hop count of the path as well as the number of control packets to create a 2-dimensional rule-base for controlling the timeout adaptively. The performance of the proposed model was compared against the performance of the original design method of AODV. Three performance metrics were used in the performance tests to validate the results. The performance analysis showed that the proposed model had a better packet delivery ratio, routing overhead and average end-to-end delay than the original method. Hence this method is shown to be advancement on the original AODV that is expected to perform better in wireless ad-hoc networks.

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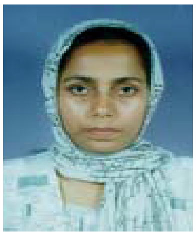

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