Fuzzy Logic End-To-End Delay Performance Over Ad-Hoc On-Demand Distance Vector Technology In Wimax Multi-Hop Network Transmission

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***Abstract*—In the present day realities and with respect to t he obvious successes recorded globally by the extensive deployment and usage of the internet and information communication technology systems, there are still peculiar challenges ranging from Quality of service (QoS)as well as other system performance issues in terms of throughput, end-to-end transmission Delay performance ratio and link utilization (Routing) It is believed that building intelligence in to system operation are evidently the best ways to enhancing system performance in process controls, routing techniques, etc. This work presents the end to end delay performance indication of fuzzy logic technology over AODV technology in WIMAX Multi-hop Mesh Network Transmission. Relevant literatures, theories and historical background based on the IEEE802.16 and IEEE802.16j standards associated with routing technique are also discussed alongside past and recent best efforts at improving WIMAX routing technique. Furthermore, the methods used in developing the fuzzy rule base and membership functions of the system are presented with the developed fuzzy model which takes as fuzzification inputs; Traffic Quality of Service (QoS) classification code based on IEEE802.16 Standards and Channel Condition of Signal to Noise Ratio (SNR)are implemented using the MATLAB Software. Finally, the fuzzy results obtained and Analysis carried out by simulations showed a significant improvement in Fuzzy WIMAX multi-hop Mesh Network End-to-End Delay performance when compared with the present day Ad-hoc on-Demand Distance Vector Routing (AODV) protocol.**

Keywords—WIMAX, MULTI-HOP NETWORK, TRANSMISSION, ROUTING, FUZZY LOGIC.

1. INTRODUCTION

The IEEE 802.16 standard, commercially known as worldwide Interoperability for Microwave Access (WIMAX), is an emerging broadband wireless access technology to provide users with high speed multimedia services. The IEEE 802.16 standard defines specifications for Medium Access Control (MAC) and Physical (PHY) layers. As reported in the literature, the main advantage of WIMAX is providing the missing link for the “last mile” connection in Metropolitan Area Networks where (DSL) cable and other broad-band access methods are not available or too expensive to deploy. It also offers an alternative to satellite internet services for rural areas and allows mobility of the customer equipment.

Wireless communication technology is expected to provide an extensive range of services with high transmission rate and enhanced Quality of Service (QoS). In the past, network applications have used a modest percentage of bandwidth and no one of those applications had QoS requirements. At that time, applications have been routed through network as Best Effort Services (BES). As reported [1] [2] [3], best effort services are not suitable for multimedia applications. Providing quality of services (Qos) to different service classes at real-time and non-real-time traffic integration is an important issue in WIMAX systems. However, the usage of high operating frequency for multimedia services introduces significant loss of signal strength along the propagation path, this limits the coverage area. This is a huge issue for a single-hop communication system as the users at cell edges will experience unstable services and low data rate. Conventional way out of these issues, as discussed in the literature, is to add another base station (BS) in the system. However, due to the high cost of deploying BS, this approach is loss favorable.

To overcome this limitation, the WIMAX specification was amended (IEEE 802.16) to include multi-hop relays an extension which has gained much attention and prove to be an attractive technology for the next-generation of wireless communications. The IEEE 802.16j amendment focus on the deployment of Relay Stations (RSs) in such a way that the network capacity can be enhanced or coverage of the network can be extended. Multi-hop Technology do offer better performance to wireless systems. However, as the number of hops increase, delay and the probability of packet loss also increase, thus degrading the throughput performance. The more number of hops, the more complex the routing computation required. Routing or path selection is one of the vital issues that should be addressed in multi-hop relay network. Routing and selecting is one of the most important scopes for improvement in WIMAX network [4].

It has been argued that much of the shortcoming of the deterministic mathematical modeling of the routing problem is anchored on the fact that these techniques do not and can hardly account for the non deterministic, the high variability and uncertainty in the wireless mesh network. Wireless transmissions are susceptible to spatial interference, and routing in multi-hop wireless network systems face significant challenges even with relatively small network sizes. The dynamics of multi-hop wireless mesh networks (such as the IEEE 802.16) are imprecise. Inference, link failure packet delays, etc in the wireless mesh network do not follow exact or deterministic trajectory and thus cannot be accurately modeled by deterministic mathematics or techniques. The routing protocols that have been presented earlier are mainly founded on exact reasoning methods, consequently they fail to meet the non linear dynamic routing requirements for improved QoS in WIMAX multi-hop mesh network systems.

Consequently to overcome the shortcoming of these deterministic routing protocols, a number of proposals [10] [11] [12] have been put forward for using stochastic routing technique. However existing formulations of stochastic routing are usually N-P hard and are not customized for wireless mesh networks.

Also, due to complexities associated with inherent inaccuracies associated with the deterministic exact reasoning techniques founded on hard computing, there is an increasing demand for more intelligent route construction techniques for WIMAX multi-hop mesh networks. Intelligent techniques fall within the domain of what is called “Soft Computing”. Soft Computing is more tolerable in uncertainty and partial truth than hard computing. Fuzzy logic, neural network, and genetic algorithm fall within the domain of soft computing.

Amply reported in the literature is the fact that fuzzy logic is a powerful problem solving methodology with wide range of applications in industrial control, consumer electronics, management medicine, expert systems and information technology. Fuzzy logic presents a simple way to draw definite conclusions from vague, ambiguous or imprecise and incomplete information. It is very close to the way human beings think and make decisions even under highly dynamic uncertain environment such as in the WIMAX multi-hop mesh network environment.

A number of studies [13] [14] have been reported to use intelligent control techniques based on fuzzy logic for solving the routing problems in WIMAX network systems. However, this fuzzy logic based routing scheme only considered such routing metrics such as required losses. They do not take into consideration the very important QoS class classification of the wireless network traffic based on the IEEE 802.16 specification.

Consequently this dissertation proposed a fuzzy logic based intelligent routing control scheme that takes into consideration the dynamic variability of channel conditions such as; Signal to Noise Ratio (SNR), link Utilization, Delay, and Traffic characteristics terms of the QoS differentiation (i.e. traffic class of service) in a WIMAX multi-hop mesh network.

1.1. BRIEF BACKGROUND HISTORY AND RELEVANT THEORIES

The problem of routing in WIMAX mesh networks has been considered in various studies. From the literature surveyed, several routing schemes have been considered in various studies. These routing schemes have been proposed for throughput improvement in WIMAX multi-hop relay networks. K. Warp et al [5] proposed route selection based on optimum throughput. They only focused on two-hop networks. Thus, users only needed to select communication with multi-hop relay base station (MRBS) directly or through RS. Routing scheme that take into account maximization of radio resource utilization is proposed by [6]. This research work managed to show that their proposed scheme is better than link-quality based scheme. However, the scheme is limited to two hops only. Routing techniques using shortest-path routing have been proposed. A good example is Dynamic Source Routing (DSR) [7]. The shortcoming of this routing protocol partly stems from the fact that it implicitly assumes that links either work perfectly or do not work at all. Furthermore being a distance vector routing protocol that relies on hop-count as its routing metric, it does not consider the link quality traffic delays, bandwidth and wireless link loss. As reported, this protocol lacks the dynamism to ensure high Qos in WIMAX multi-hop network system. The ad-hoc on-demand distance vector (AODV) protocol is one of the pre-dominant reactive routing protocols. The AODV is inherently a distance vector routing protocol. It is an on demand or reactive protocol, as it finds the routes only when required. AODV borrows basic route establishment and maintenance mechanisms from DSR protocol. It is reported [4] that AODV has some shortcoming when applied to WIMAX multi-hop mesh network. First of all, with hop-count as its routing metric, it lacks the ability to differentiate between network node types, link quality such as delays, bandwidth, and congestion. Furthermore, in addition to the fact that this protocol does not consider the non-linearity, spectral variability and inherent uncertainty of WIMAX mesh multi-hop network, the protocol does not consider QoS class differentiation of wireless networks traffic.

Furthermore the approaches, as proposed in [8], formulate the problem as a linear optimization problem where the routing problem is modeled as a mathematical problem. However this approach requires global knowledge of the network topology and the traffic matrix. Furthermore it was argued [9] that even with complete knowledge of the network topology, optimal channel assignment is very difficult to achieve and is considered an NP-Land problem.

Arianity Maray [13], Shakti Kumar et al [14], these authors in their papers proposed the use of fuzzy logic for solving routing problems in WIMAX network systems. However, this fuzzy logic based routing scheme only consid ered such routing metrics such as required resources, buffer size packet queues, delay and losses. They do not take into consideration the very important Qos class classification of the wireless network traffic based on the IEEE 802.16 specifications.

Consequently this dissertation proposes a fuzzy logic based intelligent routing control scheme that takes into consideration the dynamic variability of channel conditions (signal to noise ratio SNR, link state, delay, and traffic in terms of the Qos differentiation (i.e. traffic class of service) in a WIMAX multi-hop mesh network.

1.2. WIMAX OVERVIEW.

WIMAX stands for Worldwide Inter Operability for Microwave Access [21]. WIMAX is known as IEEE 802.16 wireless MAN Standard. As reported in the literature, the IEEE 802.16 working group was designed to support the bandwidth demanding applications with quality of service (QoS). Bandwidth is reserved for each application to ensure the quality of service. The technical literature posits that for Variable Bit Rate (VBR) application, it is however, difficult for the Subscriber Station (SS) to predict the amount of incoming data. The literature established that WIMAX was basically an effort to develop a standard for broadband wireless access in Metropolitan Area Networks (MAN). According to the technical document on WIMAX, one of the features of the MAC buyer, in this standard, is that it is designed to provide differential servicing for traffic with multimedia refinements. To ensure the QoS guaranteed services, the subscriber station (SS) may reserve more bandwidth than its demand. As a result, the reserved bandwidth may not be fully utilized all the time.

Mainly the IEEE 802.16 standard as discussed in the WIMAX technical literature can be thought of as of two types IEEE 802.16 which is specified (as documented) for fixed subscriber stations and IEEE 802.16d which supports mobility. It is reported that WIMAX devices are created to operate the three different bands; 2.5, 3.5 and 5.7 GHZ. The physical layer in WIMAX uses Orthogonal Frequency Division Multiple Access (OFDMA) Technology and the maximum data rate in WIMAX is 70 mbps. WIMAX is intended to give a coverage area of about 20 miles. WIMAX Standard reported in the literature eliminates the last mile problem and acts as an alternative to the cable and DSL technologies [22].

1.3. ALGORITHMS FOR ROUTING IN IEEE 802.16 NETWORK.

The survey of the literature revealed that authors have made much effort to discuss the problem of routing and scheduling in WIMAX systems. Various frameworks have been proposed in the literature for optimal routing and scheduling in the IEEE 802.16 network.

One of the routing schemes reported extensively is the shortest path routing scheme, where the routing is fixed over all the frames for each node. Some generalization on fixed routing are described in the literature. Assuming we have fixed the routing. Let λ_1 denote the external mean number of bits arriving at node i at the beginning of frame k, ri (k) the assigned transmission rate during frame k, θ i (k), the queue length at the beginning of frame K, Xi (k), the external arrivals; Yi (k), and the arrival from other nodes to node i at the end of frame k. Assume the schedule is fixed and node i is always assigned in slots in a frame then the queue length operation is represented by;

θ i (k+i) = (θi(k) – niri (k)$)^+$ + Xi (k) + Y: (k)……(1)

for the queue to be stable, a necessary condition is;

ni E (ri) > E (Xi +Yi) = λi +E (Y)………(2)

where E [Yi] is under the stationary distribution of the system if it exist.

The authors in [25] and [26] posited that for fixed, having loops is obviously not efficient. Also, splitting traffic from a node along two paths to MBS is not optional unless both the routes have the same cost it also assumes that giving the whole traffic to one path will not make it worse (because the channel schedule can be accordingly adjusted). These, together imply that we make a tree structure. Then, E (Yi)= $\sum^{mi}_{j=1}$ □ai,j, where; [ai,I,ai,z,az,mi] are the nodes whose data pass through node I, hence, eqn.(2) becomes.

ni > λi + $\sum^{mi}_{j=1}$ λai,j, for all i =1,…,m …….. (3).

The literature clarified that for a tree network, this is a necessary and sufficient condition for the overall system to have a unique stationary distribution even when the arrival streams [Xi(k)] and the channel rates [ri(k)] are allowed to be stationary, ergodic.

Since, $\sum^{mi}_{j=1}$, n, =N, from (3) we get;

$\sum^{mi}_{j=1}$ λi+$\sum^{mi}_{j=1}$$\lambda$ai,j < i …………..(4)

In fact if (4) is satisfied, then we can find a fixed allocation scheme that can stabilize the system. Rearranging the terms in (4), we get $\sum^{hi}_{j=1}$ _1_ ... (5)

E [rpi,j]

the overall stability region can be maximized. This argument motivates the short path routing scheme, where the routing is fixed over all the frames for each node along a path that minimizes;

$\sum^{hi}_{j=1}$ _1__ ,….(6).

E [rpi,j]

The literature proposes that if the routing is fixed, then the shortest path routing explained above is optional in the sense that it maximizes the stability region of the system. Another way to look at this routing is that it minimizes the average work needed to transmit a packet from a node to the MBS (for an uplink). This should also be a routing which provides the minimum delay. The report makes clear that in the class of fixed routing and scheduling algorithms, this indeed is the optional routing.

Instead of fixed routing, the literature advocates the use of dynamic routing changing the route for a packet depending upon channel conditions along a path and the queue lengths. It is stated in the surveyed literature that this is assumed in the system, however, is not really practiced because loops require re-sequencing as a distinction. Also, according to the authors [25] and [26], providing end-to-end QoS through resource reservation is difficult.

2. THE AD-HOC ON-DEMAND DISTANCE VECTOR (AODV) PROTOCOL

The ad-hoc on-demand distance vector (AODV) protocol is one of the predominant reactive ad-hoc routing protocols. AODV was originally developed for homogenous mobile ad-hoc networks, where nodes typically have a single corrects network interface and have comparable computational communication resources. Consequent, AODV has some shortcoming when applied to WIMAX multi-hop relay networks. As the literature reported, first of all, with hop-count as its metric, it lacks the ability to differentiate between node types, i.e. thus it is unable to exploit the interleague retry in the network. Furthermore, it is reported that AODV is not aware of the wireless channels used for the network integrates and, therefore, it cannot minimize co-channel interference and maximize the use of multiple orthogonal channels between node pairs.

2.1. FUZZY LOGIC CONTROLLER

Much has been written on the use of fuzzy logic controllers in process control and in intelligent network systems. Fuzzy logic (FL) controllers based on fuzzy set have been extensively reported in the literature as a paradigm used to represent the experience and knowledge variables that are called fuzzy rules.

The studies on fuzzy logic theory have increased tremendously since its development by Zadah [35]. The literature survey shows that the application of fuzzy logic theory to a control system by Mandani and his colleagues [36] has given to the fuzzy logic real word applications.

The operational principle of a fuzzy logic controller is similar to a human operator. It performs the same actions as a human operator does by adjusting the input signal relative to the system output. A fuzzy logic based controller consists of three sections namely fuzzifier, rule base, and defuzzifier as shown in fig. 1, below;

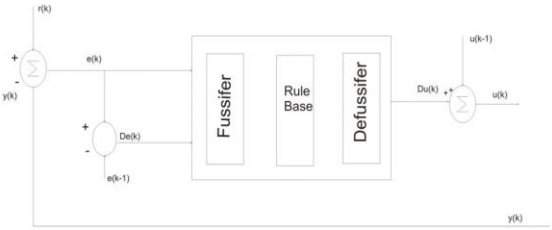


Fig.1:The basic structure of fuzzy logic based controller.

Two input signals; the main signal and its change for each sampling, the fuzzy logic controller is converted to fuzzy numbers first in fuzzifier. Then they are used in the rule table to determine the fuzzy number of the compensated output signal. Finally, the resultant united fuzzy subjects representing the controller output are converted to the crisp values.

The fuzzy logic controller is designed to act as an integrator controller such that the resultant incremental output Du (k) is added to the previous value v (k-1) to yield the current output v (k). Recalling the digital solution of an integrator using Euler's integration relation;

V (k)=v(k-1) +Du(k) ….. (7)

In a digital integration, the term Du(k) is expressed as;

Du (k) = $K_1 T_s$ C ……….(8).

Where K_1 is integral constant, T_s is sampling period, and 'C' is the integration signal. The change Du (k) on the output of an integrator becomes zero when the input 'C' is zero. Therefore output of an integrator retains the previous value. Hence, (7) can be used for both an integrator and fuzzy logic controller. The difference between an integrator and fuzzy logic controller is the method that is used to obtain Du(k), which is obtained using equation (8) is used for an integrator, while the fuzzy interference system shown in figure 1, is used for the fuzzy logic controller.

3. RULE-BASED FUZZY MODELS

In rule based fuzzy systems, the relationship between variables are represented by means of fuzzy if-then rules of the following general form:

If, antecedent proposition, then consequent proposition. The antecedent proposition is always a fuzzy proposition of the type "X is A" where X is a linguistic variable and A is a linguistic constant (term). The proposition's truth value (a real number between zero and one) depends on the degree of match (similarity) been x^2 and A depending on the form of the consequent. Two main types of rule based fuzzy models are distinguished.

- Linguistic fuzzy model: Both the antecedent and the consequent are fuzzy propositions.
- Takagi-Sugeno (TS) fuzzy logic: The antecedent is a fuzzy proposition while the consequent is a crisp function.

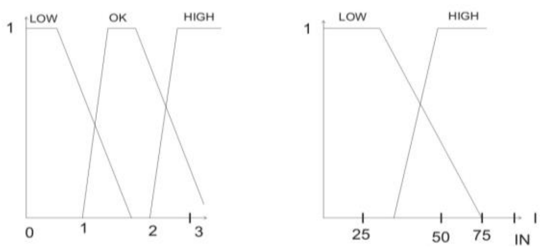
3.1. LINGUISTIC FUZZY MODEL

The linguistic fuzzy model has been introduced as a way to capture available (semi) qualitative knowledge in the form of if then rules.

Ri: If x is Ai then Y is Bi = 1,2,.

Here; x is the input (antecedent) linguistic variable, and Ai are the antecedent linguistic terms (consequent) similarly, Y is the output (consequent) linguistic term. The values of x (Y) and the linguistic terms Ai (Bi) are fuzzy sets defined in the domains of their respective base variables XEXCE and YEYCR. The membership functions of the antecedent (consequent) fuzzy sets are then the mappings. X(x): X (0,1); X(Y): Y (0,1). Fuzzy sets Ai define fuzzy regions in the antecedent space, for which the respective consequent propositions hold. The linguistic terms Ai and Bi are usually selected from sets of predefined terms, such as small, medium, etc. by denoting these sets by A and B respectively, we have Ai EA and Bi E B. The Rule Base "R" = {Ri/i = I, 2.k} and the sets A and B continue the knowledge base of the linguistic model. The meaning of the linguistic terms is defined by their membership functions as depicted in figure 2 The numerical values along the base variables are selected somewhat arbitrarily. Note that the literature indicates that no universal meaning of the linguistic terms can be defined. Nevertheless, the qualitative relationship expressed by the rules remains valid.

In order to be able to use the linguistic model, we need an algorithm which allows us to compute the output value, given some input value. This algorithm is called the fuzzy inference algorithm (or mechanism) for the linguistic model; the inference mechanism can be derived by using fuzzy relational calculus



4. NETWORK PARAMETERS USED AS FUZZY ANTECEDENT AND CONSEQUENT ATTRIBUTES TO THE DESIGN MODELING.

Let S be a set of attributes (i.e. S= ∑X, Y, =.e}) that determines attribute Z (i.e. the set S contains a set of antecedent attributes, and Z is a consequent attribute) since this design uses FCLS, selecting different elements in the sets as root node, may result in consulting different kinds of fuzzy decision tree.

For this design the WIMAX multi hop network route selection is highly dependent on: signal to noise ratio (SNR) i.e. channel condition, Average packet delay and packet loss rate. All these referenced from the network traffic class. The goal of analyzing these network variables to arrive at the route i.e. the next Multi-hop Relay Base Station (MRBS).

Hence the fuzzy antecedent attribute for the design are signal to noise ratio (SNR), average packet delay and packet loss rate.

i.e. S = ∑ SNR, …. (9)

SRN = signal to noise ratio,

Dj= the average packet delay of J class

S= packet loss rate.

The consequent attribute is the next hop (preferred route) to the MRBS (refer to figure 2).

4.1. AVERAGE PACKET DELAY

The delay of a packet is defined as the total time spent by the packet to flow through the network uplink channel (UL). Denoted by Djk, the delay of the k^{th} packet of priority class j is; [19]

$$D^j_k = W^j_k + r + P.{}^j_t \quad FL... (10)$$

Where W_k denotes the packet waiting time, r represents the total time to transmit a priority J/k^{th} packet. FL denotes the Packet frame latency. P denotes the packet propagation delay. The average packet delay of J class is D given by:

$$D=W_j ; 1+ E_j . B \frac{N-1}{N} \frac{N}{ni} . r +^j_k FL+ P_k ....(11)$$

ni = slot per frame

E = duration of time slot

N = number of frame time slots.

Bj, is the second moment of service time and is given by; Bj, = $\int_o x^2 dBF(x)$.(12)

P_k = λj B_j . 1,2,3 ……n,…… (13)

ni =∑ P_i, J = 1,2, 3 .n, ….(14)

Where J, is the priority index .etc

Where; $$Wj, 1 =\sum \lambda j\ bi, 2+(1-nj) \frac{N}{ni} r^j \ ...... (15)$$

'J' is the priority index which takes values from 1 to n depending on the traffic class. P_i is the traffic intensity and bj 1, is the first moment of service time [17]

The frame latency can be calculated by, F_i= frame size as bit rate (bits/s)

The propagation delay is assumed in this design to be negligible.

4.2. PACKET LOSS RATE

The packet loss occurs when one or more packets traveling across a network fail to reach its destination. A packet from the source is correctly received by the destination, only if it is not dropped from the queue (with probability) $[1\text{-}I\text{-}P]^d$, and it is correctly received through the wireless channel (with probability [1-PER]). Hence, the probability of a packet received correctly is ([1-Pd](1-PER]), and the packet loss rate can be expressed as [18]:

$S = I - (I - P_d)\ (I\text{-}PER)$…. (16)

$P_{d,}$ denotes the packet dropping probability which is due to its queue being full. It is defined as the ratio of the number of dropped packet E [D] over the number of arrived packet E [A] during the scheduling period. It can be expressed as: P_d=E{D}.(17). E{A}

Where λT, is the packet of arrival packets rate upon the queue at the subscriber station;

E {D} = Lim - I ∑ Dt ….(18)

T t=1

Where D_t is the number of dropped packets at time "t". It can be expressed as;

D_t =Max {O, A_t - f_t}…..(19)

Where A_t is the number of arrived packets at time t and ft in the number of arrived packets at time t and Ft is the number of free slots in the queue at the beginning of time t. It is assumed [18] that;

E {A_t} = λT_f …………(20),

PER denotes the packet error rate of the wireless transmission channel and can be expressed as [19]. YBS_{min} is the minimum SINR requirement of the BS receiver. Parameters; a_n and g_n are modulation and coding mode dependent, which can be determined by the modulation and coding scheme and it is provided subsequently.

4.3. MEASUREMENTS AND DATA COLLECTION

Table 1, shows the data values obtained from the simulations carried out in the course of the Design and Evaluation of the work.

AODV DELAY		FUZZY DELAY	
Time(s)	Delay	Time(s)	Delay
0	0	0.0227	0.0007
0.4234	0.008	0.3856	0.0024
0.746	0.0248	1.1568	0.0047
1.1089	0.0297	1.7011	0.0073
1.4718	0.0403	2.9259	0.0095
1.996	0.049	3.4249	0.0122
2.0766	0.0465	3.561	0.0122
2.1976	0.0539	4.2414	0.014
2.2782	0.0533	4.7858	0.0153
2.9637	0.0707	5.5116	0.0175
3.2056	0.0688	5.8745	0.0202
3.6492	0.085	6.1013	0.0202
3.7298	0.0806	6.3281	0.0202
3.8911	0.0868	6.691	0.0228
4.0121	0.085	6.9632	0.0228
4.0927	0.0955	7.689	0.0264
4.2944	0.093	7.9612	0.0264
4.3347	0.1017	8.0973	0.0273
4.7379	0.1061	8.4148	0.0286
4.9395	0.1061	9.0045	0.0308
5.2621	0.1154	9.3674	0.0321
5.3024	0.121	9.7303	0.0335
5.504	0.121	10.0479	0.0335
5.8669	0.1241	10.5922	0.0344
5.8669	0.1272	11.1366	0.0357
5.9879	0.1253	11.8624	0.037
6.2298	0.1328	12.6336	0.0401
6.3105	0.1321	13.0418	0.0401
6.3508	0.1365	13.7223	0.0428
6.4718	0.134	14.5388	0.0454
7.0363	0.1477	14.9924	0.0459
7.3185	0.1464	15.5822	0.0485
7.5605	0.1526	16.0811	0.0499
7.6815	0.1526	16.6709	0.0508
8.125	0.1619	17.3967	0.0512
8.4476	0.1663	18.0771	0.053
8.8105	0.1663	18.5307	0.0539
9.254	0.1799	19.0751	0.0561
9.7379	0.1855	19.6648	0.0583
10.0605	0.1892	20.2999	0.0614

Table 1: AODV Delay/Time standard tabulation against the fuzzyDelay/Time corresponding values obtained.

5. DATA ANALYSIS

The simulation is carried out to evaluate the delay in the routing of packets in the multi hop Wimax model. These parameters are obtained for the fuzzy routing control and for the distance vector (AODV) routing control. The distance vector routing control algorithm is included as part of the MATLAB library. The fuzzy logic performance is compared with that of the distance vector routing algorithm. Below, are the various graphical representations obtained and the comparative analysis and explanation.

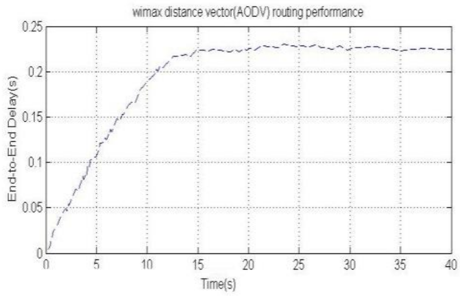


Fig.3. WIMAX Distance Vector (AODV) performance plot as obtained using the MATLAB

FIG.4. The WIMAX Fuzzy logic performnce plot as obtained using the MATLAB

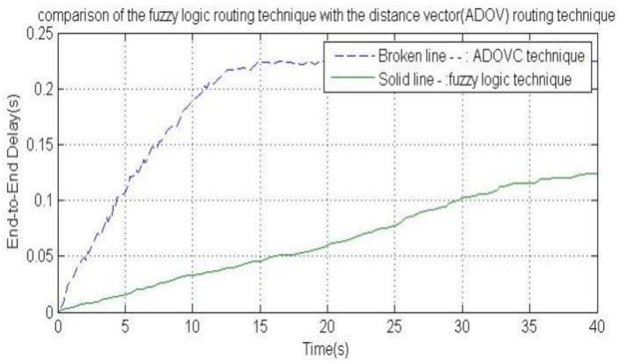


Fig.5. The Comparism of the two different graph plots (in figs. 3&4 above)using MATLAB

5.1. SUMMARY OF GRAPHICAL ANALYSIS.

Figure 3 and figure 4 show the routing delay in the network under the control of the distance vector routing protocol and the one under the control of the fuzzy logic routing technique. From the figures 5, it can be seen that the distance vector protocol produces a higher end-to-end delay compared to the fuzzy routing techniques. This shows that the delay in a routing packet in the Wimax multi-hop relay base station is higher with the distance vector routing technique compared to the fuzzy logic technique. This difference is shown clearly by figure. The fuzzy routing technique performs better due to the fact that it considered the channel quality and link capacity of the base station in all the paths to the multi-hop relay base station.

5.2. CONCLUSION AND RECOMMENDATION

Wimax based on the IEEE 802.16 standard offers a lot of advantages where DSL, cable and other broadband access methods are not available or too expensive. Routing and scheduling is one of the major issues in the improvement of Wimax networks. Routing in WIMAX multi-hop network system will have significant impact on the performance of the network and will largely decode the end-to-end quality of service (QoS) to different users.

A number of routing techniques have been proposed for Wimax. These proposed routing protocols are deterministic and do not take into consideration the variability of the network topology, the channel sensitivity and the quality of services, while some others employ complex computational technique that have been found to be N-P hard(not possible in polynomial term). Fuzzy logic is a powerful problem-solving methodology with wide range of application in industrial control, expert systems. Fuzzy logic presents a simple way to draw definite conclusions from vague, ambiguous or imprecise and incomplete information. Hence this paper proposes the development of a fuzzy logic based routing algorithm for Wimax multi-hop relay network improvement.

MATLAB was used to model the WIMAX test network. Simulation was carried out to evaluate the end-to-end delay. The fuzzy logic routing controller showed reduced end-to-end delay. The performance of the fuzzy logic algorithm was compared with AODV (ad-hoc on-demand distance vector routing protocol), the result showed that the fuzzy controller has a lower end-to-end delay than AODV. The fuzzy routing techniques as can be seen in the plots produced low end-to-end delay.

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