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Fuzzy logic based packet scheduling algorithm for Mobile ad-hoc Network with a realistic propagation model

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***Abstract*— in this paper, we propose a priority based scheduling algorithm for Mobile Ad-hoc Network (MANET) using fuzzy logic. The fuzzy system has three inputs: data rate, Signal-to-Noise Ratio (SNR) and queue size. The fuzzy system was verified using MATLAB fuzzy toolbox and the performance of the algorithm was evaluated using OPNET simulator. The results were compared to an existing fuzzy scheduler. The measuring metrics which form the basis for the performance evaluation were end-to-end delay, throughput and packet delivery ratio. The proposed scheduler performed better than the existing scheduler; an average improvement of 37% for end-to-end delay, 56% for throughput and 57% for the packet delivery ratio. However, this comes at the cost of additional computational complexity. The existing fuzzy scheduler injects an additional packet processing time of 46ns whilst the proposed scheduler injects 165ns.**

Keywords- OPNET; SNR; MANET

I. INTRODUCTION

A Mobile Ad-hoc Network (MANET) comprises of randomly distributed mobile nodes that form a network without the need of a control centre or infrastructure. MANET has many useful applications, e.g. disaster relief, military operation, and most recently civilian applications which include environmental monitoring, healthcare etc. The transfer of data between MANET nodes is peer-to-peer in nature. A pair of mobile nodes can communicate directly when they are within radio range of each other. Hence, in order for a particular source to transmit data to a destination outside of its transmission range; the source node must relay this data through one or multiple intermediate peer(s) to reach the required destination. This phenomenon is called multi-hop, which is a special characteristic of MANET.

As a result of the dynamic nature of node movement, there are frequent disconnection between nodes which are connected either directly or indirectly [1][2].

As MANETs gain popularity, the need for support of real time and multimedia applications has increased. These applications have Quality of Service (QoS) requirements such as throughput, end-to-end delay and packet delivery ratio [3][4]. The QoS provision for MANET is provided over various layers in the Open Systems Interconnection (OSI) protocol stack. The first is the physical layer; it is responsible for the quality of transmission. The link layer takes care of the variable bit error rate. The change in delay and bandwidth is the responsibility of the network layer. The transport layer deals with the delay and packet loss due to transmission, whilst the application layer is concerned with the regular disconnection and reconnection of the network link [5].

The random nature of the node mobility cause frequent route changes and as a result leads to high packet loss and end-to-end delay; it can also decrease network throughput. Since, there is no infrastructure to assist in packet transmission; it is difficult to maintain a specified QoS target. All nodes in MANET have the capacity to be a source, sink or just a relay. Thus, as a result of the various functionalities of a node, data will produce varying queuing behavior, which is different from a traditional wired network. Hence by using a scheduling algorithm to determine what queue or packet needs to be served next, the overall network performance can be improved. The default scheduling scheme for packets in MANET is First In, First Out (FIFO).

A great deal of research has been done to improve the QoS of MANET. Research paper such as [6] focused on routing protocols to improve link stability, end-to-end delay and bandwidth optimisation. Paper [7] proposed an efficient coding scheme for the dissemination of data between MANET nodes. Paper [8][9] compared the performance of various routing protocols with regards to mobility, delay, packet loss and network congestion and [10] discussed the link stability in MANET.

Paper [11], used a fuzzy inference system with two input variables and a single output(priority index). The two input variables are channel capacity and data rate; these were used to determine the priority index of packets to be scheduled. Paper [12] also did some work on fuzzy scheduling with MANET (based on buffer size and number of hops suffered by packet). Based on [11] we explored a better way to improve the QoS of MANET. In the course of this paper, [11] will be referred to by the first name of the first author which is Manoj and it will form the basis for performance evaluation.

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This paper proposes a fuzzy based scheduler that schedules individual packets based on its priority index. This priority index for the individual packets was calculated by considering three input variables, which were data rate, queue size and SNR. The fuzzy scheduler was developed in OPNET simulation environment using C language. The proposed scheduler improved the overall end-to-end delay, throughput and packet delivery ratio of the network.

This paper contains six sections. Section II defines Quality of service (QoS) and some of its measuring metric. It also explains scheduling schemes and some currently available schemes. Section III describes the fuzzy scheduler. Section IV explains the performance analysis, it also presents the results and discussion; finally the conclusion is presented in section V.

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II. QUALITY OF SERVICE (QOS)

QoS is the networks ability to provide better service for selected traffics. Some of the network features used to measure the QoS are delay, throughput and packet delivery ratio. These features are used as the measuring metric for performance analysis in this paper. Scheduling schemes are used to improve the quality of service in networks.

A. Scheduling Scheme

To improve the quality of service of MANET, a scheduling scheme is required. This is an algorithm that determines the order in which a thread or data flow can access the available resources. Packets from various flows arrive at a node, and the scheduler is used to treat individual flow fairly in order to improve the quality of service. Some of the conventional available scheduling algorithms are FIFO, Priority Queuing (PQ) and weighted fair queuing (WFQ); these algorithms are designed to improve the QoS of a network [13]: In FIFO: various packet flows are kept in the buffer until they are ready to be processed by the queue. Packets that arrived first at the queue are served first and any other packet that arrives afterwards will have to wait in the queue until all previous packets have been served. If the average packet arrival rate is greater than queue processing rate, the queue will not be able to cope with the intensity of packet arrivals, thus congestion will occur. Hence packets will be discarded by the queue either because the queue buffer is already full or it has exceeded the waiting threshold in the queue.

III. FUZZY SCHEDULING SYSTEM

A. Fuzzy Logic

Fuzzy logic is a system that implements the human experiences and preferences with membership functions and fuzzy rules. It can be use as a general methodology to incorporate knowledge, heuristics or theory into controllers and decision making [12]. Fuzzy model is made up of four blocks, these blocks comprise of a fuzzifier, defuzzifier, inference engine and fuzzy knowledge base as show in Figure 1.

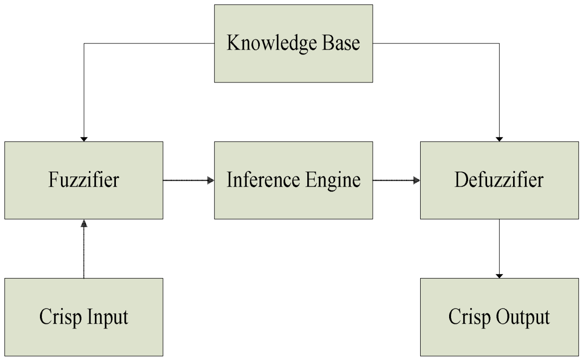

Figure 1: Basic Fuzzy System

B. Fuzzy Scheduler

The proposed fuzzy scheduler had three input variables and a single output which is the priority index of each packet. In this model, all the inputs considered contributes to congestion (both internally and externally), unlike previous fuzzy scheduling schemes. The three inputs of the fuzzy model are Data rate, queue size and SNR of individual nodes that the packet is associated with as shown in Figure 2. The inputs are fuzzified, implicated, aggregated and defuzzified to obtain the crisp value which is the output i.e. priority index.

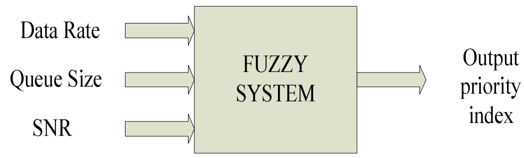

Figure 2: Fuzzy Scheduler

There are a number of membership functions, these includes trapezoidal, triangular, piecewise linear, Gaussian and singleton. The most commonly used membership functions are trapezoidal, triangular and Gaussian Shapes. The type of membership function can be context dependent and is chosen arbitrarily by the user depending on their level of experience. In this paper, for simplicity, the triangular membership function was chosen to represent the input and output variables except for the high data rate where a trapezoidal membership function was used. The linguistic variables associated with the input variable are low (L), medium (M) and high (H). For the output priority index, 5 linguistic variables were used. They are, very low (VL), low (L), medium (M), high (H) and very high (VH).

The conditional rule for the fuzzy scheduler is shown in Figure 3 and Figure 4 shows the surface viewer. The first rule can be interpreted as if (SNR is low) and (Data rate is high) and (queue size is high), then the priority index is very low. The output priority index ranges from 0-1, ‘0’ meaning the highest priority in the queue. Thus as the priority index increases from 0-1 the packet priority in the queue drops accordingly. The three input variables (with three associated linguistic variable (low, medium, and high) have 3^3 combinations, prompting the 27 rules.

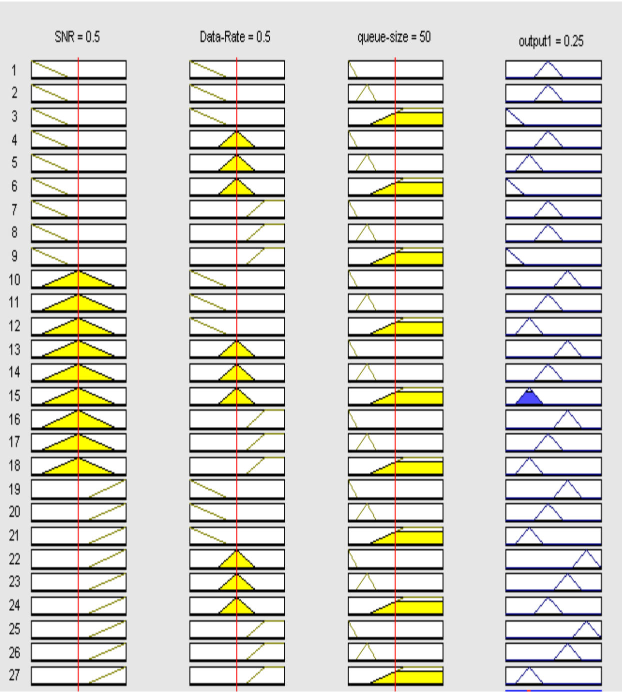

Figure 3: Membership Function and fuzzy rule base for fuzzy scheduler

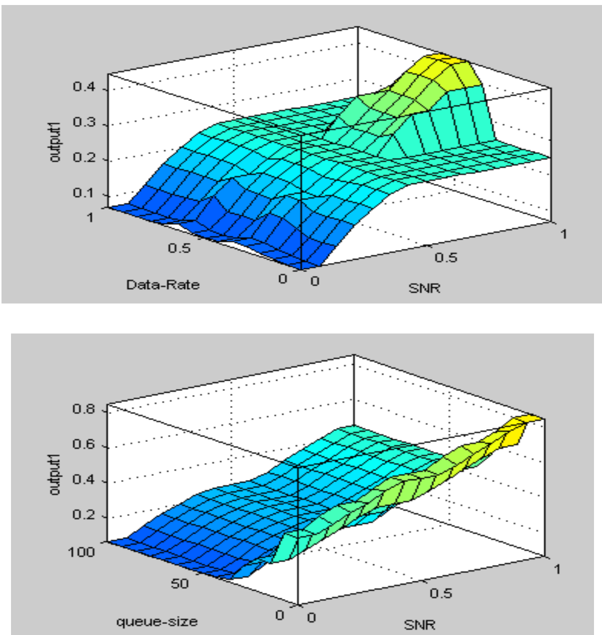

Figure 4: Surface viewer for Fuzzy Scheduler

IV. Performance Evaluation

The proposed fuzzy logic algorithm is evaluated using a network simulation model called OPNET and the measuring metric was end-to-end delay, packet delivery ratio and throughput. The results are presented in this section.

A. *Simulation Environment and Methodology*

OPNET is the leading simulation tool used in the academic circle for simulation of computer network and relevant technologies. It is used for modeling (designing) and analyzing communication networks. It can model the performance of a simulated system with a high degree of accuracy.

This simulation, models a network of randomly distributed mobile nodes within a 500 x 500 area. The mobile nodes have wireless interfaces, which were configured to the IEEE 802.11n standard. The wireless interconnection speed varies between 12Mbps-54Mbps. A shadowing propagation model with path loss exponent (β) of 2.02 and a shadowing deviation (α) of 6.5 was used according to previously carried out outdoor experiment. Each of the simulations was run for 600 seconds and multiple run with varying seed values was done and the collected data was average. Table 1 shows the simulation parameters used. A traffic generator which generates Variable-Bit-Rate (VBR) was developed. The data flow for VBR traffic changes with time. These changes are normally smooth, not sharp and sudden. For this type of flow, the average data rate and the peak data rate are different. This traffic type is more difficult for the network to handle as opposed to constant traffic, because it can not readily predict the allocated bandwidth needed for the date flow [14]. Examples of such traffics are compressed video and voice streams. All mobile nodes served as a transmitter and receiver. The size of the data payload was 1024bytes/packet. The performance of the scheduler was evaluated under various load condition (30, 40, 50 and 60 pkts/s). The random waypoint mobility model was used and the node speed ranges from 0-20m/s with a pulse time of 4s.

Table 1: Simulation Parameters

No. of Nodes	20
Area	500*500
Simulation Time	600 sec
Mobility Model	Random waypoint
Speed	0-20m/s
Propagation model	Shadowing model
Traffic Type	VBR
Channel Bandwidth	12-54Mbps
Data payload	1024bytes/packet
MAC protocol	IEEE 802.11n

B. *Performance Evaluation of Fuzzy Scheduler*

The priority index of individual packet was calculated using fuzzy logic. The input to the fuzzy logic was SNR, data rate and queue size of the node in which the packet is present. This way, both the internal and external factors that determine the QoS of a network are considered.

The input was obtained from the network and the fuzzy rules were evaluated based on these inputs. Each evoked rule has a corresponding output membership function. This output membership function was then implicated, aggregated and the crisp value (priority index) was calculated from these aggregated curves by using a defuzzification method called centroid. The C algorithm which implements the fuzzy system was verified using the fuzzy logic tool box in MATLAB.

C. Performance Evaluation using OPNET

The calculated priority index of a packet is used to schedule the packet. By scheduling the packets this way, packets in highly congested queues were scheduled first. The scheduler constantly monitors the data rate, queue size and SNR of transmitting nodes to determine the best priority index for individual packets arriving the queue. This differs from the regular priority scheduler because the packet priority index was based on individual packet rather than a traffic flow. If the queue of a node is full, it will cause an increase in end-to-end delay and packet loss as new arriving packets are discarded and packets already in the queue, that have exceeded the waiting threshold are also discarded from the queue, resulting in poor QoS. There are many factors which contribute to the poor performance of a network; it is not limited to the queue size alone, but also includes the data rate and SNR. When the SNR is low, it means the network will suffer a higher packet loss as a result of the wireless communication link between nodes; with this algorithm packets are given higher priority when there is a drop in the SNR in order to reduce the packet loss rate and thus improve the end-to-end delay.

The final input which is the data rate of transmission was normalized. At a higher data rate, the end-to-end delay of a packet is low and the packet delivery ratio is significantly higher, however when the reverse is the case, there will be a higher packet loss rate and an increase in the end-to-end delay. Packets are given a much higher priority when the data rate is low. Packets present in a crowded node will experience a high queue delay and probably a higher packet loss rate; however this algorithm monitors some of the factors responsible for this and tries to optimize the network to improve its QoS performance. When a packet reaches a node its priority index based on the network properties of that node is calculated and attached to its header file. Each node has three sub-queues and packets are en-queued in these sub-queues based on their priority index. When the packet arrives the queue of a node, it is sorted based on its priority index (packet with the lowest priority index move to the top of the queue and is scheduled first when next the node transmits). Using this scheduling method the overall performance of the network was increased.

D. Performance Analysis of Fuzzy Sceduler

The performance of the fuzzy system was evaluated by comparing it to an existing fuzzy model [11] (Manoj). Manoj considered data rate and channel capacity; however from previously carried put test and simulation models, mobile nodes in OPNET can not transmit at the maximum channel capacity rather at an effective channel capacity which is much lower. Thus using the channel capacity will not give the accurate statistic needed. Manoj scheduler was faster than the proposed fuzzy scheduler. This was because, it considered just two input variables with 3^2 rule whilst the proposed scheduler considered three input with 3^3 rule. The proposed scheduler was more computationally complex because of the number of rules. As a result of the different level of complexity of both scheduler algorithm; each of the algorithm were run in Microsoft Visual Studio for a 100 cycle, a timer was inserted at the beginning and end of the C code to measure the time taken to run each cycle and the average time was calculated. Manoj algorithm took an average time of 46ns to execute each cycle whilst the proposed algorithm took an average time of 165ns to execute each cycle. This average time was regarded as the additional processing delay both algorithms will add to the network. It was added as a constant value to the formulae that calculates packet processing delay in OPNET. Manoj did not consider this additional processing delay. Manoj algorithm was approximately 3.5 times faster than the proposed algorithm. However the proposed algorithm compensates for this by optimally scheduling packets in the network much better than Manoj. This can be seen in the results presented below.

The average end-to-end delay for the traffic generation rate of 30pkts/s is shown in Figure 5 as a function of simulated time. As can be seen, the proposed fuzzy scheduler performed better than the existing one. The performance of the proposed fuzzy scheduler in the first 0-30 seconds is slightly lower than Manoj, the performance however improved significantly from simulation time 30-600 seconds. The limited resources of the network can not cope with the intensity of packets arriving at the queue, as a result congestion occurred. This is the reason why the average end-to-end delay increased linearly with time. The behavior of the delay graph for 40pkts/s is shown in Figure 6 which is similar to 30pkt/s. 50pkt/s and 60pkts/s also develop similar trait to Figure 5 and Figure 6. The values for the average end-to-end delay for 30pkts/s, 40pkts/s, 50pkts/s and 60pkts/s are shown in Table 2.

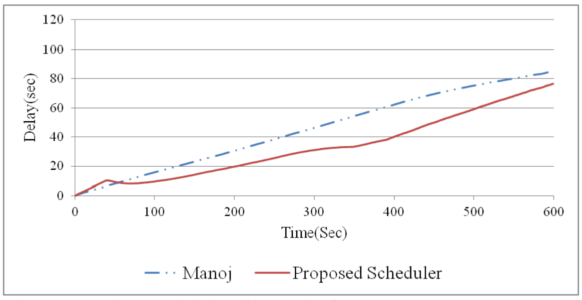

Figure 5: End-to-End delay for 30pkts/s

From Table 2, the proposed scheduler performed 26.85% better than Manoj for 30pkts/s, 43.33% better for 40pkts/s, 42.78% better for 50pkts/s, and 34.21% better for 60pkts/s. The performance of the algorithm gets much better as the network load increased from 30-40-50pkts/s but drop slightly for 60pkts/s. The gradient gets steeper as more packets arrives the queue.

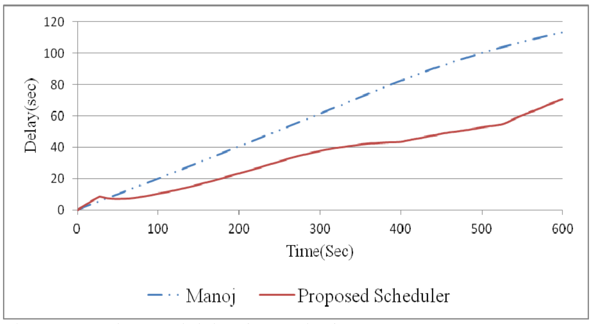

Figure 6: End-to-End delay for 40pkts/s

The gradient of the end-to-end delay graph shows the rate of increase of congestion. As the gradient increases the network tends towards congestion, therefore to avoid congestion or prevent a severe case of congestion the gradient needs to be low. For Manoj, the network becomes congested more quickly because of its high rate of change. The proposed fuzzy scheduler has a lower gradient than Manoj. For 30pkts/s as shown in Figure 5, the gradient of the proposed fuzzy scheduler is 18.60% less than Manoj, thus the network congestion is reduced by 18.60%. The gradient of the proposed algorithm was also 45.60% and 48.75% lower than Manoj for 40 and 50 pkts\s respectively. The performance slightly dropped to 33.92% for 60pkts/s.

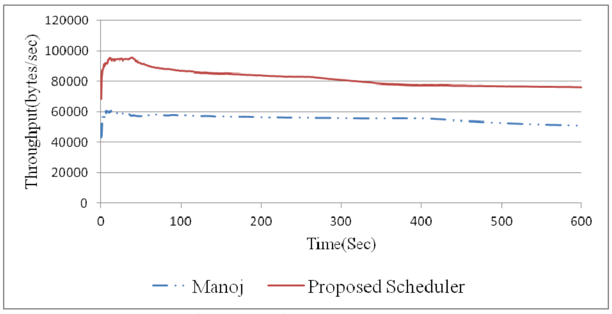

Figure 7: Throughput for 30pkts/s

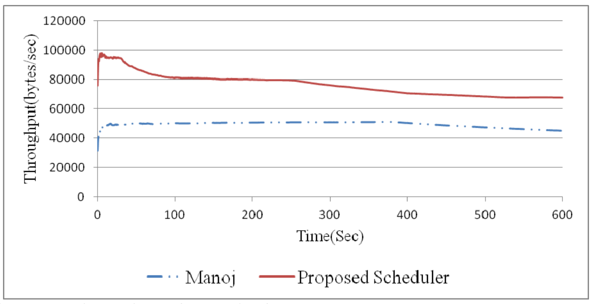

Figure 8: Throughput for 40pkts/s

Figure 7 shows an improvement in the throughput for 30pkts/s and Figure 8 shows that of 40pkts/s. From Table 3, it can be seen that the percentage improvement of the throughput increases as the network load increases. There was an increase of 47.32%, 54.16%, 55.55% and 66.47% in throughput for the proposed scheduler for 30, 40, 50 and 60pkts/s respectively.

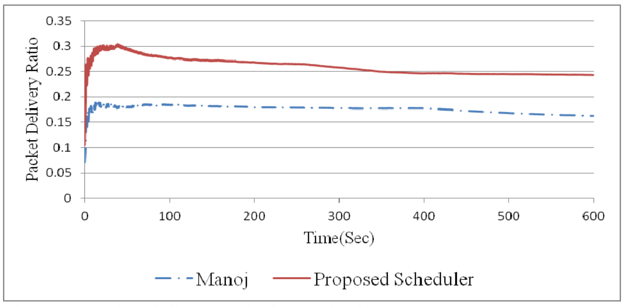

Figure 9: Packet delivery ratio for 30pkts/s

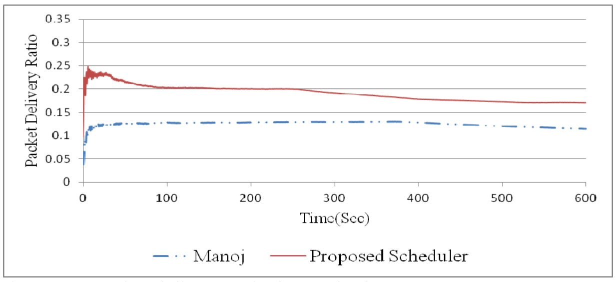

Figure 10: Packet delivery ratio for 40pkts/s

Figure 9 shows an increase in the packet delivery ratio for the proposed scheduler with regards to that of Manoj for 30pkts/s. The packet delivery ratio for 40pkts/s is shown in Figure 10. Table 4 shows the proposed fuzzy scheduler, has a higher packet delivery ratio than the Manoj as can be seen from the % improvement. That is, the proposed scheduler delivered an average of 44.44% more traffic than Manoj for 30pkts/s, 46.15%, 66.67% and 71.43% more traffic for 40, 50 and 60pkts/s respectively.

Table 2: Average End-to-End Delay

Scheduler	**Average End to End delay (s)**			
	30	***40***	***50***	***60***
Manoj	45.59	60.50	69.96	77.17
proposed	33.35	34.29	40.03	50.77
diff	12.24	26.22	29.93	26.40
% improve	26.85	43.33	42.78	34.21

Table 3: Throughput

Scheduler	**Throughput (bytes/s)**			
	30	***40***	***50***	***60***
Manoj	55592	49540	46747	43277
Proposed scheduler	81895	76370	72717	72044
diff	26303	26829	25970	28766
% improve	47.32	54.16	55.55	66.47

Table 4: Packet Delivery ratio

Scheduler	**Packet Delivery ratio**			
	30	***40***	***50***	***60***
Manoj	0.18	0.13	0.09	0.07
Proposed scheduler	0.26	0.19	0.15	0.12
diff	0.08	0.06	0.06	0.05
% improve ~	44.44	46.15	66.67	71.43

V. CONCLUTION

This paper proposed a new fuzzy scheduler algorithm for MANET and compared it with an existing fuzzy scheduling algorithm. It considered three inputs (data rate, queue size, SNR) as opposed to the existing scheduler, which considered two inputs (data rate and channel capacity). However according to previous simulation work, individual mobile nodes in OPNET can not transmit at the maximum channel capacity rather they transmit at an effective channel capacity which is much lower. Thus using the channel capacity as an input, will present some level of inaccuracy in calculating a packet priority index. The inputs to the fuzzy system were fuzzified, implicated, aggregated and defuzzified to obtain the crisp value. The crisp value is a number that ranges from 0-1 and it represents the packet priority index. Zero '0' meaning the highest priority and 1 meaning the least priority, therefore as the priority index increases from 0-1 the priority of the associated packet in the queue decreases. Each node consisted of three sub-queue; individual packets are inserted in this sub-queues based on their priority index and also served in the queue accordingly. The performance of the scheduler was analyzed using measuring metric such as end-to-end delay, throughput and packet delivery ratio.

A test was carried out using Microsoft visual studio to estimate the additional processing time both algorithms will add to the network. An extra 46ns in packet processing time was added to Manoj while an extra 165ns in processing time was added to the proposed algorithm. These values were added as a constant value to the queue processing time of individual packet. The membership functions and the fuzzy rule base were carefully designed, thus triangular and trapezoidal membership functions were chosen for simplicity. The algorithm was implemented in OPNET and the coding was done in c and verified using the Fuzzy toolbox in MATLAB. Although the proposed scheduling algorithm was more computationally complex than Manoj, it however performs significantly better than the existing scheduler; an average improvement of 37% for end-to-end delay, 56% for throughput and 57% for the packet delivery ratio. This algorithm compensates for its complexity by optimally scheduling the network much better than Manoj.

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