Priority based Fuzzy Decision Multi-RAT Scheduling Algorithm in Heterogeneous Wireless Networks

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Summary
In this paper, we focus on the scheduling algorithm of heterogeneous wireless networks where the traffic has different requirements constrains which are needed to be fulfilled without exceeding the internal constrains of the node . We propose a priority based Fuzzy decision packet scheduling algorithm which is mainly based on delay, channel quality conditions, type of call (Handoff or new call) and classes of service. Using those parameters as an input, the Fuzzy logic approximates decision making using natural language terms instead of quantitative terms. The inputs to the Fuzzy system are fuzzified, implicated, aggregated and defuzzified to obtain the crisp value which represents the packet priority index. The simulation of the presented method is performed using Matlab and the results show that the presented scheme satisfactorily performs the system requirements and they prove that inclusion of the Fuzzy approach on the scheduler improves the packet drop ratio and minimize the end-to-end delay.

Key words:
Scheduling algorithm, heterogeneous wireless networks, Priority, Fuzzy, end-to-end delay

1. Introduction

In recent years, mobile networks have developed dramatically to offer a large variety of services like video downloading, internet browsing and interactive gaming, etc. The Quality of Service (QoS) like packet loss ratio and packet delay are demanded by these services. To satisfy these requirements, high data rate should be provided by the mobile network. Several research works have been conducted in order to provide QoS in heterogeneous wireless networks using different scheduling approaches. Scheduling support is one of the motivating features of the future HWN. In scheduling, the QoS architecture treats packets differently by offering guaranteed services to the mobile user. Scheduling presents a decision-making problem that includes optimization of scheduling criteria. Due to the distributed nature of HWNs, nodes may not be able to decide the next packet to be served and must satisfy QoS requirements of the users. So a novel priority scheduling approach using Fuzzy logic that addresses these aspects is proposed.

Fuzzy logic is a rule-based decision paradigm that aspires to solve problems where the system is difficult to model and where vagueness or uncertainty is superabundant between two extremes [1]. Fuzzy logic allows the system to be defined by natural language expression rather than complex differential equations [2]. In scheduling, the Fuzzy logic approximates decision making using natural language terms instead of quantitative terms [3]. Fuzzy scheduling algorithms were proposed for real-time tasks in computing [4].

In this paper, we propose a novel Fuzzy scheduling mechanism called PFDMS (Priority based Fuzzy Decision Multi-RAT Scheduling algorithm) based on Fuzzy-logic rules that operates in HWN. We introduce four inputs such as packet delay, channel quality, type of calls and of services to decide the output Priority index.

The paper is organized as follows. In section I, the introduction is introduced. In section II, the related work of this research is summarized. Section III illustrated the Fuzzy system and the proposed approach followed by simulation results in section IV. Finally the conclusion and the future scope of the presented scheme are discussed in section V.

2. Literature Review

The emerging and exponential growth of telecommunication networks have developed a variety of smart devices handling different multimedia traffic such as Voice over IP (VoIP) and video streaming which aims at achieving significantly higher rates [5].

A great deal of research has been done to improve the QoS wireless networks. Recent research such as [6] focused on the problem of balanced energy consumption among sensor nodes. In [6], Shah and al. propose Fuzzy controller algorithms to guarantee a pre-configured lifetime. They focus on how to guarantee the previously-determined or pre-configured wireless sensor network's lifetime. In order to achieve this, they endorse a strategy where each node consumes energy approximately at the optimal energy consumption rate.

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Recent research such as [7] addressed problem of scheduling in Long Term Evolution-Advanced (LTE-A), Mansouri and al. propose a Mobility Aware downlink scheduling algorithm (MAS) and compare it with Round Robin and Best-CQI algorithms in terms of throughput, fairness and Block Error Rate (BLER). In [8], Ben Abdelmula and al. analyze the performance of two deployments LTE-A network with Carrier Aggregation (CA) scenarios and they showed the limitations of the existing scheduling algorithm. The proposed algorithm which is based on channel variations does not consider QoS requirements.

In [9], Radhakrishnan and al. have reviewed the most important packet scheduling algorithms such as modified Proportional Fair (PF), Modifid Largest Weighted Delay First (M-LWDF), Blind Equal Thoughput (BET) etc., for real time traffics in the LTE-A networks. They have analyzed the key features of these algorithms and the scheduling metrics have been given. The eNodeB uses both CA and Multi Input and Multi Output features to take a scheduling decision based on QoS parameters and buffer status.

In many related works, scheduling problem are addressed [10] and [11]. In the work [10], Huang and al. proposes an adaptive ordering predicting scheduling. This scheme estimates packets' arrival orders at the receiver side through multiple paths and then derives packets' transmission schedule at the sender side.

Research [12], concentrate on dynamically adjusting the parameters of CSMA/CA according to the traffic rate and the queue buffer size. The proposed algorithm uses some parameters through a Fuzzy logic system based on the IEEE802.15.4 MAC protocol. A priority scheduling is allocated to the nodes according to their queue length and traffic rate measurement. This algorithm does not take into consideration some other important parameters such as the channel quality and the expiry time of each packet.

Other works using Fuzzy logic are proposed in literature like [13] where Egaji and al. proposed two optimised Fuzzy logic scheduling algorithms for the Mobile Ad Hoc Network (MANET). The performance of these schedulers was compared to an existing Fuzzy scheduler. Both schedulers consider three inputs (Data rate, queue size, and Signal-to-noise ratio (SNR)).

In [14], Poonguzhali have proposed a Fuzzy-based simple and efficient resource allocation technique for allocating dynamic grid resources to the submitted jobs. Work [15] proposed a new Fuzzy scheduler algorithm for MANET that schedules individual packets based on its priority. This priority index is calculated based on three input variables which are data rate, queue size and SNR. The proposed scheduling algorithm in [15] is based on the data size and the required bandwidth. The channel and network condition is also analyzed. In [16], Othman and al. proposed a new scheme which selects the Channel Quality Indicator (CQI) from a range of quantized CQI intervals based on the speed of the user equipment. They propose an adaptable mapping of CQI values to the SINR that decreases the required power from the eNode-B.

3. Setting priority using fuzzy

3.1 Theory of Fuzzy System

Since Lotfi Zadeh introduced it, Fuzzy Logic has become the best way to manipulate ambiguous systems [17]. Fuzzy logic is a rule-based decision paradigm that aspires to solve problems where the system is difficult to model and where vagueness or uncertainty is superabundant between two extremes [1]. Fuzzy logic allows the system to be defined by natural language expression rather than complex differential equations. Fuzzy logic systems are mainly composed of Fuzzy subsets, Fuzzy rules and inference mechanism. The Fuzzy subsets represent different sets of the input and output variables. The Fuzzy rules accomplished with the Fuzzy Inference System (FIS) are the way of mapping an input to an output variables using Fuzzy logic [18]. Given a set of Fuzzy rules, accompanying the inference mechanism the system can compensate quickly and efficiently. Nowadays, Fuzzy logic and Fuzzy ideas is applied in many systems like engineering, controlling medicine, and many systems where uncertainty influential. In [19], an adaptive neuron-fuzzy inference system is used to build two intelligent models for forecasting the PM10 concentration.

Fuzzy interpretations of data sets are a very natural and intuitive way of authenticating and solving various Conventional method (i.e., crisp) sets contain objects that satisfy precise properties required for membership. For example the set S of closed interval in real numbers between 5 to 9 is crisp; is written S= $\{r \in \Re \mid 5 \leq r \leq 9\}$, where $\Re$ is the set of real numbers. Otherwise, S is described by its membership (or natural description) function (MF), $\mu H : \Re \rightarrow \{0,1\}$, defined as:

$$\mu_H = \begin{cases} 1 & 6 \leq r \leq 8 \\ 0 & otherwise \end{cases} \qquad (1)$$

Every real number (r) is either in S or not. Here μ_H maps all real numbers $r \in \Re$ into only two points 0, 1, crisp sets correspond to a two-valued logic: True or False, Black or White, On or Off, 1 or 0. In Fuzzy logic, values of $\mu_H$are called degree of truth with reference to the question, "Is r in S?" The answer is value between 0 and 1, 0 for non belongness and 1 for the full belongness and a value in-between based on mathematical calculation equivalent to natural language expression i.e equivalent membership function MFs.

3.2 Input of Fuzzy System

Expiry time

In this paper, we propose a scheduler based on priority Fuzzy decision which chooses to schedule the packet that has the earliest time to expire and the best channel conditions, among all the packets. Each packet n has deadline $D_{max,n}$. Some constraints must be guaranteed:

- The end-to-end delay $D_{max,n}$ of real-time packets must be met,
- To guarantee the deadline, the packet must leave the network before the expiration of the offered delay $D_{i,j}$ of the access technology i (RAT(i)) must be met. Assume that the network i contains n_i nodes, the local deadline of packet n in each intermediate node k in the path is then calculated as follows:

$$d_{i,k}^{n} = \frac{D_{i,j}}{n_i} \quad (2)$$

Using the same method presented in [20], we determine the residual delay is calculated as follows:

$$\Delta_{i,k} = \begin{cases} 0 & for\ k = 1 \\ \frac{D_{i,j}}{n_i} - \left(A_{i,k}^{n} - A_{i,k-1}^{n}\right) & for\ k > 1 \end{cases} \quad (3)$$

Then, the deadline in each node is as the following:

$$d_{i,k}^{n} = \frac{D_{i,j}}{n_i} + \Delta_{i,k} \quad (4)$$

The expiry time is the remaining time before the deadline of the packet expires. It is based on the waiting time in each router. Then, the waiting time of the nth packet in the buffer of router k is calculated as in [7]:

$$W_{i,k}^{n} = \sum_{l=1}^{h_{n,k}} D_{tr,l} \quad (5)$$

Where $D_{tr,l}$ is the transmission delay of packet l and $h_{n,k}$ is the set of packets that have higher priority than the nth packet in router k. Then, the exactly earliest expiry time:

$$\delta_{i,k}^{n} = D_{max,n} - \left(A_{i,k}^{n} - t_{i,n}\right) - W_{i,k}^{n} \quad (6)$$

Where $A_{i,k}^{n}$ is the time when the nth packet arrives at the router k in the RAT(i) and $t_{i,n}$ is the time when the nth packet arrives at the first router of its path.

Channel Quality

The channel is in one of the three states, namely, high, medium or low, at any time instant. If the estimated SINR is larger than a threshold denoted as γ, the channel is considered good.

For low interference, the channel is considered "high" channel

$$SINR \geq \gamma \quad (7)$$

The channel is considered "medium" channel if:

$$\gamma > SINR \geq SINR_{req} \quad (8)$$

For high interference, the channel is considered "low" channel.

$$SINR < SINR_{req} \quad (9)$$

Type of Call

In this work, we consider one more parameter which presents the type of the call: handoff or new call. This classification helps us to give more priority to handoff call.

Class of service

We also consider that the traffic is classified into two classes. The first class is for Real Time traffic (RT) which involves voice and live video applications. The second class is Non-real Time traffic (NRT) for data.

3.3 Proposal System

The architecture of the proposed system is shown in Figure 1. The first step in building the system is to determine the input that affects the node priority index which are:

- Expiry time
- Channel quality (based on the SINR)
- Type of call (Handover, New call)
- Class of service (Real Time, Non Real Time)

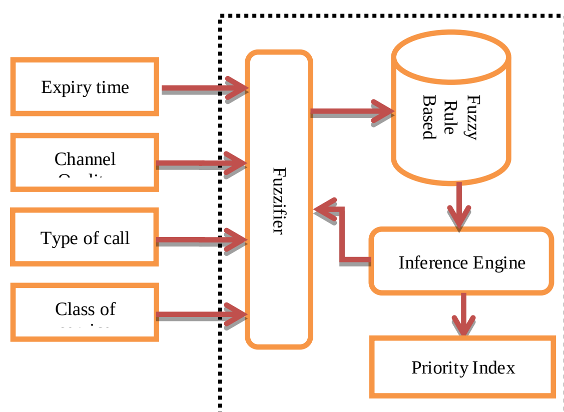


Fig.1 System Architecture

The second step in our system architecture is input/output fuzzification. In this step, crisp values are turned to membership values using exquisite membership functions. The membership functions must be created by the system designers. A membership functions are mathematical functions that defines the degree of membership of a crisp input data and turn it to a linguistic variable [19]. Depending on their shapes, membership functions can take different form of representations. The membership functions in fuzzification processes used in our system are Trapezoidal, Gaussian and Triangular curves. Figure 2 shows the four inputs and the output MFs where TC and TS are represent Type of Call and Type of Service respectively.

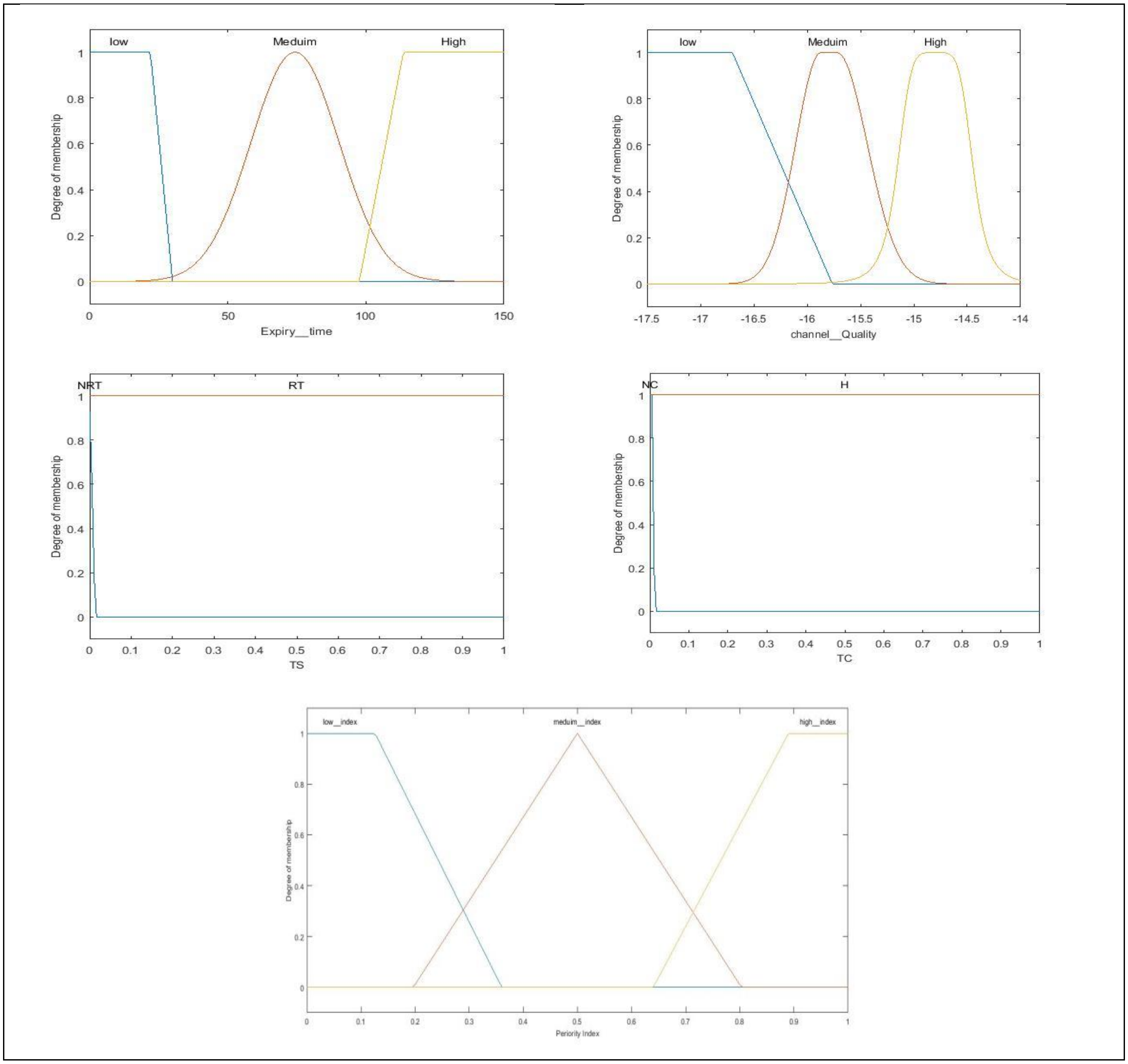


Fig. 2 System input/output membership functions

The trapezoidal MFs used for the input and output fuzzification is given by the following formula:
Trapezoidal MFs:

$$f(x,a,b,c,d) = max\left(min\left(\frac{x-a}{b-a},1,\frac{d-x}{d-c}\right),0\right) \quad (10)$$

The triangular MFs used for the inputs and output fuzzification given by the following formula:

$$f(x,a,b,c) = max\left(min\left(\frac{x-a}{b-a},\frac{c-x}{c-b}\right),0\right) \quad (11)$$

Where a, b, c and d are the premise parameters that characterize the shapes of the inputs and output MFs.

The Gaussian MFs used for inputs fuzzification given by the following formula:

$$f\left(x,c_i,\sigma_i\right) = \exp\left(\frac{-(c_i-x)^2}{2\sigma_i^2}\right) \quad (12)$$

Where ci and σi are the center and width of the ith Fuzzy set xi , respectively.

The third step in our proposed system is rule construction. Fuzzy rules can be considered like: IF x1 is A1 and x2 is A2 ... and xn is An THEN y1 is B1 and y2 is B2 ... and ym is Bm, Aij and Bjk are linguistic variables. The rules are based on two conditions: "if" and "then" consequent action mechanism, which is established for development of a Fuzzy Logic System to identify the priority index. The number of Fuzzy rules base will be equal to 22 +23= 12 and the index will be divided into three classes (high, medium, low). The rules base for the priority index will have the following form:

- If (Expiry_time is low) and (channel_Quality is High) and (TS is RT) and (TC is H) then (output1 is low_index)
- If (Expiry_time is low) and (channel_Quality is High) and (TS is RT) and (TC is NC) then (output1 is low_index)
- If (Expiry_time is low) and (channel_Quality is High) and (TS is NRT) and (TC is H) then (output1 is high_index)
- If (Expiry_time is low) and (channel_Quality is High) and (TS is NRT) and (TC is NC) then (output1 is high_index)
- If (Expiry_time is low) and (channel_Quality is low) and (TS is RT) and (TC is H) then (output1 is high_index)
- If (Expiry_time is low) and (channel_Quality is low) and (TS is RT) and (TC is NC) then (output1 is high_index)

Also in this step, the computation of weighting factor for each rule is performed. The weighting factor ωk is determined by evaluating the linguistic expressions membership in the antecedent of the rule. This is accomplished by first converting the input values to Fuzzy membership values by using the input MFs in the step1 and then applying the “and” to get minimum value to these membership values. The “and” operator corresponds to the multiplication of input membership values. Hence, the weighting factors of the rules can be computed as follows:

$$\begin{aligned} \omega_1 &= M_{11}(W)\, M_{21}(L)\, M_{31}(h)\, M_{41}(\varepsilon_r) \\ \omega_2 &= M_{11}(W)\, M_{21}(L)\, M_{31}(h)\, M_{42}(\varepsilon_r) \\ \omega_3 &= M_{11}(W)\, M_{21}(L)\, M_{31}(h)\, M_{43}(\varepsilon_r) \\ \omega 4 &= M_{11}(W)\, M_{21}(L)\, M_{31}(h) M_{44}(\varepsilon_r) \end{aligned} \quad (13)$$

Where Mij, represents the jth MF of the ith input.

Step 4: In this step, the implication of each output MF is computed by

$$M_{imp,k} = w_k z_k \quad , k = 1, \dots, n \quad (14)$$

Where Mimp,k and Zk represent the output MFs [12] and the output of the kth rule.

Step 5: In this step, the aggregation is established to produce an overall output MF, Mo(z), this can be done by using the union operator:

$$M_o(z) = \bigcup_{k=1}^{n} M_{imp,k} = \bigcup_{k=1}^{n} w_k Z_k \quad (15)$$

The two types of the output MFs (Mok) are trapezoidal and triangular. Hence, the “union” operation is performed by using of the minimum operator.

Step 6: In this layer, the defuzzification is performed by the most widely used defuzzification method which is centroid of area:

$$z = \frac{\sum_j^q z_j u_c\,(z_j\,)}{\sum_j^q u_c\,(z_j\,)} \quad (16)$$

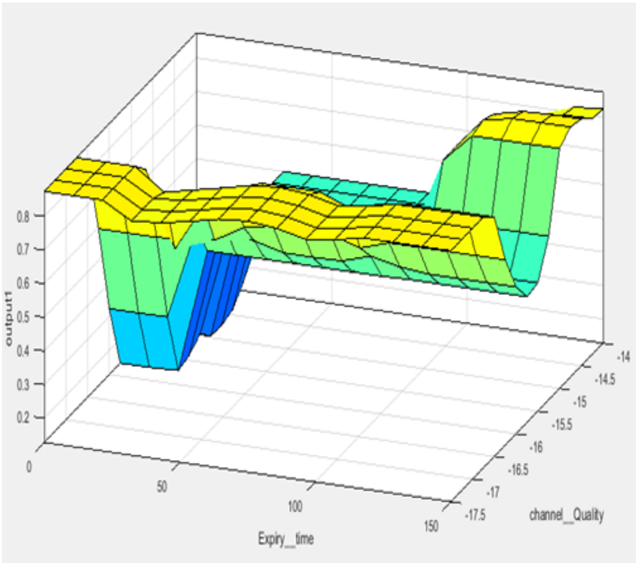
Where z is the center of mass and uc is the membership in class c at value zj.

Scheduling algorithms determine which packet has the priority to be served next among the packets. If the output priority index is very low, it indicates that packet has a very high priority so it should be directly scheduled. In the same way, if the priority index of the packet is very high, it will be attached with least priority and will be served only after all high priority packets. The proposed algorithm can be written as follows:

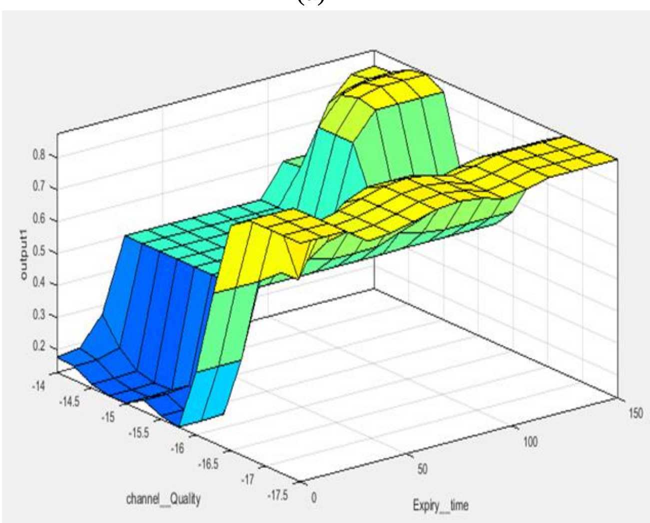
Input: Expiry Time, Channel Quality (SINR), Type of Service, Type of Call
Assumptions: The two first inputs are in 3 scales (H, M, L).
Output: Priority index
Combine the packet deadline, the channel quality, the type of service (RT, NRT) and the type of call (H, NC) with FIS to calculate the priority index of the packet

Algorithm 1: Setting up the priority

The conditional rule for the Fuzzy scheduler is shown in Figure 3. Figure 4 shows the surface viewer.



(a)



(b)

Fig. 3 Surface viewer for Fuzzy Scheduler

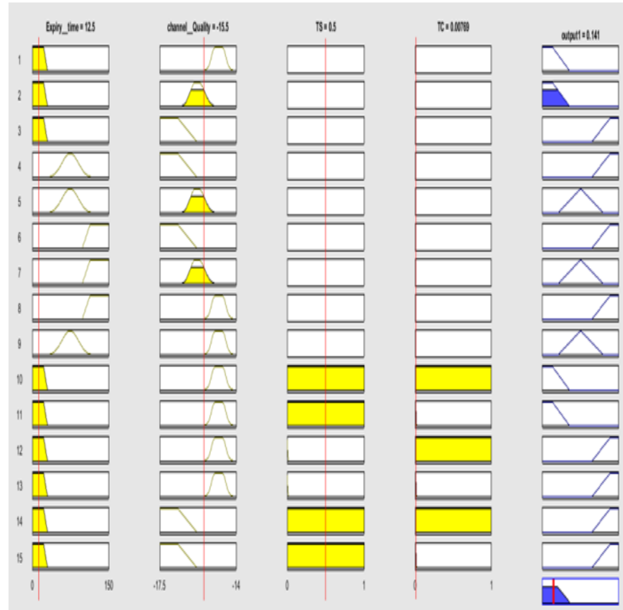


Fig. 4 Rules viewing

The first rule can be interpreted as if the channel quality is considered good between -14 and -15,75 and the expiry time of the packet is low (under 50ms) then the index priority is low which means that those packets have higher priority compared with the other packets with bad channel quality. The output priority index ranges from 0 to 1, ‘0’ means the highest priority in the queue.

4. Performance evaluation

The simulation for evaluating the Fuzzy scheduling scheme was realized within the Matlab. One of the most vital inputs to the Fuzzy system is the expiry time which presents the deadline of the packet. If this variable is used as an input to the scheduler for finding the priority index, a packet with a very low deadline value (expiry time) is given the highest priority. The next input to our scheduler is the channel quality, which is categorized into good, medium or bad quality based on the estimated SINR of the channel. The third input introduced in the modified Fuzzy scheduler, is the type of service which can be Real Time or Non Real Time. The forth input present the type of call which can be Handoff or New Call. The priority index is calculated based on these four inputs.

The scheduler is set of three queues. In each queue, packets are sorted based on the priority index. Packets with the lowest priority index (which are packets with the highest priority), are scheduled next.

This simulation, models a network of randomly distributed mobile nodes within a 1000 x 1000 meter area. In this article, we consider real-time and non real-time traffics. Real Time applications (RT) require a limited delay. Non Real Time applications (NRT) are not exigent in term of delay. We assume that the mean arrival rate of New Calls follows a Poisson process with parameter λ1 for the VoIP service and λ2 for the data service. Interactive users follow the WWW model described in [22] with an average of 5 pages per WWW session and 30s reading time between pages.

Table I shows the simulation parameters for LTE, WLANs and WMNs.

Table I: Main Simulation Parameters

	LTE	***WMN***	***WLAN***
Bandwidth	10MHz	10MHz	22MHz
Path loss exponent α	3	3	3
Data rate	100 Mbps	300 Mbps	11 Mbps
Transmit power	46 dBm	20 dBm	20 dBm
Radius	500 m	50 m	50 m
$SINR_{req}$ (RT)	-4 dB	12 dB	5.5 dB
$SINR_{req}$ (NRT)	-4 dB	9 dB	5.5 dB
Packet size (RT)	120 bytes		
Packet size (NRT)	1500 bytes		
λ_1: Call rate (RT)	10 calls/s		
λ_2: Call rate (NRT)	5 calls/s		
Average call length (RT)	180s		
Average call length (NRT)	600s		
Movement speed	1 m/s		
T_{RT} :Transmission rate(RT)	12.2 kbps		
T_{NRT} :Transmission rate (NRT)	64 kbps		
Handoff deadline	32 ms		
Simulation time	30 minutes		

The following metrics are used to evaluate the new Fuzzy scheduler:

- Packet loss ratio.
- Average packet waiting time.

The inputs of our system are carefully chosen and the rule base is written with due care in order to improve the performance metrics of scheduler in the heterogeneous wireless networks. The membership functions are also suitably designed accordingly. In this method of scheduling, the determination of priority index packets is based on the expiry time of the packet, the channel conditions, type of call and class of service. Packet with the lowest priority index (highest priority) will be scheduled immediately.

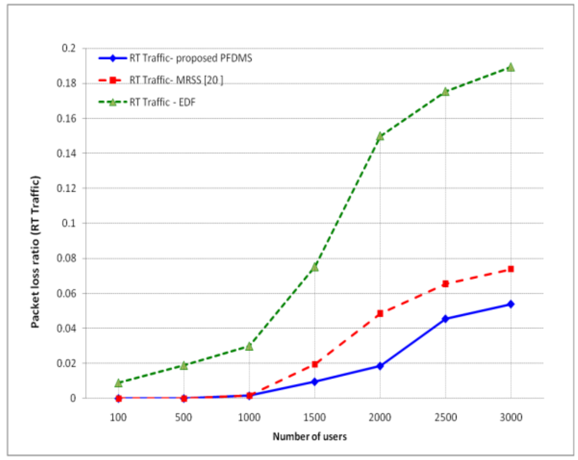


Figure. 5 Packet loss ratio for Real Time (RT) Traffic

From figure 5, it is seen that the packet loss ratio for RT traffic of the algorithm Earliest Deadline First (EDF) and the algorithm MRSS proposed in [20] reach higher loss ratio than our proposed scheme. The packet loss ratio improves further when run with our proposed Fuzzy priority scheduler called PFDMS. Consequently, serving RT packets with the highest priority based on Fuzzy system minimize the number of packets dropped due to deadline expiry and channel quality.

The packet loss ratio of our PFDMS is lower than scheme in [20] and the EDF because of the fact that the channel quality is taken into consideration and the packets are served immediately if the quality is good or medium. Packets are served fast before the expiry of its end to end delay. For example, the packet loss ratio of our PFDMS is 0.19 when the number of users is 2000, where the existing algorithm [20] is 0.49 for the same number of users. As seen in the figure 5, from the number of users 1000 until 3000 users, our priority Fuzzy algorithm outperforms the existing scheme [20] with the low values of packet drop ratio.

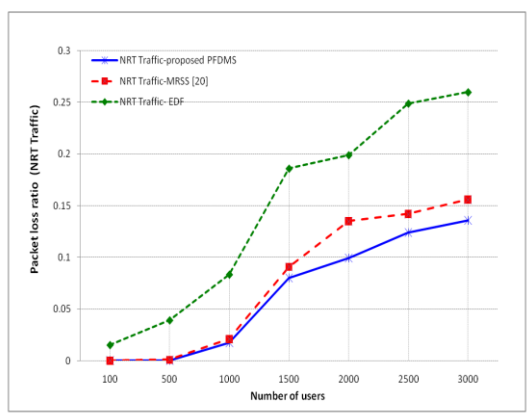


Fig. 6 Packet loss ratio for Non Real Time (NRT) Traffic

The same results are obtained for the NRT traffic when varying the number of users as shown in Figure 6. Our priority Fuzzy algorithm outperforms the existing algorithm without Fuzzy system. Thus, the packet drop ratio for the existing scheme reaches higher values compared with our proposed algorithm.

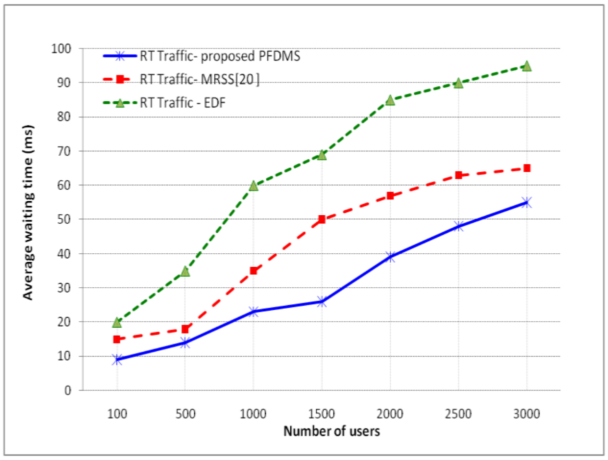


Fig. 7 Average waiting time

The performance of a scheduling algorithm is measured by its capability to keep all delays below the deadline. In Figure 7, we illustrate the average waiting time versus the number of users in the different RATs. As can be seen, the average end-to-end delay for the traffic of our proposed Fuzzy scheduler performed better than the existing one. The proposed Fuzzy scheduler has a lower delay than the existing scheduler. For example for 1000 users as shown in Figure 7, the average waiting time of the proposed Fuzzy scheduler is 24 ms less than the scheme in the reference [20]. The average waiting time of the proposed algorithm was also 55 ms lower than the existing one for 65 ms when the number of users increases in the network to 3000 users.

5. Conclusion

Fuzzy logic was introduced as a mathematical way to represent uncertainty in everyday life. It has been introduced to deal with vague, imprecise and uncertain problems. This is why Fuzzy logic is widely employed in telecommunication applications. In this paper, we used a Fuzzy logic system and we proposed the priority based Fuzzy decision Multi-RAT scheduling algorithm in heterogeneous wireless networks considering the input such as expiry time of packets, channel quality, type of service and type of call.

We conclude that the presented Fuzzy scheduler yield better results when compared with existing algorithms that does not use Fuzzy system. Our proposed algorithm can be useful in different wireless networks with a large number of nodes. In future work, more improvements and modifications may be performed on the Fuzzy rules.

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