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An intelligent scheduling system using fuzzy logic controller for management of services in WiMAX networks

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Abstract The appearance of media applications with high bandwidth and quality of service requirements has made a significant impact in telecommunications technology. In this direction, the IEEE802.16 has defined wireless access systems called WiMAX. These systems provide high-speed communications over a long distance. For this purpose some service classes with QoS requirements are defined; but the QoS scheduler is not standardized in IEEE802.16. The scheduling mechanism has a significant effect on the performance of WiMAX systems for use of bandwidth and radio resources. Some scheduling algorithms have been introduced by researchers; but they only provide some limited aspects of QoS. An intelligent decision support system is therefore necessary for scheduling. In this paper a fuzzy based scheduling system is proposed for compounds of real-time and non-real-time polling services which provide QoS requirements and fairness in dynamic conditions. A series of simulation experiments have been carried out to evaluate the performance of the proposed scheduling algorithm in terms of latency and throughput QoS parameters. The results show that the proposed method performs effectively regarding both of these criteria and achieves proportional system performance and fairness among different types of traffic.

Keywords IEEE802.16 · WiMAX · Fuzzy scheduling · Services management · Bandwidth assignment · QoS guarantee

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1 Introduction

The IEEE 802.16 standard [1, 2], known as WiMAX, is one of the most popular standards for fixed and mobile broadband wireless access systems. Some advantages of this standard are: simplicity, low-cost deployment, high-speed data rate, last mile wireless access, and QoS support for multimedia applications [13].

The IEEE 802.16 Medium Access Control (MAC) specifies five types of QoS classes [2]: Unsolicited Grant Service (UGS), real-time Polling Service (rtPS), extended real-time Polling Service (ertPS), non-real-time Polling Service (nrtPS), and Best Effort (BE) QoS classes. Each service related to a type of QoS class can have different constraints such as the traffic rate, maximum latency and tolerated jitter.

UGS supports real-time services that have fixed-size data packets on a periodic basis. rtPS supports real-time service flows that generate variable data packets sizes on a periodic basis. ertPS is built on the efficiency of both UGS and rtPS. The Base Station (BS) provides unicast grants in an unsolicited manner like UGS. Whereas the UGS allocations are fixed in size, the ertPS allocations are dynamic. nrtPS is designed to support non-real-time services that require variable size bursts on a regular basis. BE is used for best effort traffic where no throughput or delay guarantees are provided. However, the IEEE 802.16 standard does not specify the scheduling algorithm to be used. Sellers and operators have to choose their own scheduling algorithm(s) to be used [12].

In this paper a scheduling system based on Fuzzy Logic is introduced. In our approach, we address the problem of head-of-line (HOL) Latency control for real-time applications and throughput control for non-real-time applications. The Fuzzy Interclass Scheduler (FIS) decides to assign bandwidth for each connection due to the dynamic condition of each customer and system knowledge base. In practice, this helps network providers to deliver a guaranteed QoS to customers while decreasing starvation of others and maximizing network utilization.

The remainder of the paper is organized as follows: Sect. 2 gives an overview of previous works in scheduling algorithms. Section 3 represents design of the proposed scheduling mechanism. Section 4 describes implementation of the Fuzzy Interclass Scheduler (FIS) policy. Simulation results are presented in Sect. 5, where the performance of the FIS and other scheduling schemes are compared. Finally, concluding remarks are given in Sect. 6.

2 Previous works on WiMAX scheduling algorithms

Some scheduling algorithms have been proposed for WiMAX. The Round Robin (RR) scheduler is studied in [4, 6]. It distributes channel resources to all the Subscriber Stations (SSs) without any priority. The RR scheduler is simple and easy to implement. However, this technique is not suitable for systems with different levels of priority and systems with strongly varying sizes of traffic.

An extension of the RR scheduler, the Weighted Round Robin (WRR) scheduler, based on static weights and Earliest Deadline First (EDF) are proposed in [5].

In [3] a Deficit Round Robin (DRR) scheduler is used for the SS scheduler. The DRR scheduler associates a fixed quantum (Qi) and a deficit counter (DCi) with each flow i. At the start of each round and for each flow i, DCi is incremented by Qi. The head of the queue i is acceptable in queuing if DCi is greater than the length of the packet waiting to be sent (Li). In this case, DCi is decremented by Li. At each round, at most one packet can be sent (and then queued) for each flow.

In [11] a scheduler for BS is developed in the uplink direction, by using a token bucket algorithm to characterize traffic flows.

A maximum signal to interference ratio (mSIR) Scheduler is based on the allocation of radio resources to subscriber stations which have the highest Signal to-Interference Ratio (SIR) [6]. This scheduler allows a highly efficient utilization of radio resources. However, with the mSIR scheduler, the users with a small Signal to Noise Ratio (SNR) may never be served.

The Temporary Removal Scheduler (TRS) involves identifying the packet call power, depending on radio conditions, and then temporarily removing them from a scheduling list for a certain adjustable time period T_R. The scheduling list contains all the SSs that can be served at the next frame. When T_R expires, the temporarily removed packet is checked again. If an improvement is observed in the radio channel, the packet can be topped up in the scheduling list again, otherwise the process is repeated for another T_R duration. Under poor radio conditions, the whole process can be repeated up to L times at the end of which the removed packed is added to the scheduling list, independently of the current radio channel condition [6].

The Opportunistic Deficit Round Robin (O-DRR) scheduler [7] is used for upstream. The BS polls subscribers periodically. After each period, the BS determines the set of subscribers that are acceptable for transmitting and the required bandwidth. A number of conditions such as that the queue should not be empty and the received SNR should be above a minimum threshold are verified by an SS. Once these conditions are satisfied, the subscriber can be accepted to transmit during a given frame of the current scheduling epoch. The scheduled set changes dynamically depending on the wireless link state of subscribers. At the beginning of each scheduling epoch, the BS resets the acceptable and scheduled sets and repeats the above-mentioned process.

The TRS can be combined with the RR scheduler. The combined scheduler is called TRS + RR. For example, if there are k packet calls and only one of them is temporary removed, each packet call has a portion equal to $1/(k-1)$ of the whole channel resources and it can be associated with the mSIR scheduler called TRS + mSIR. This scheduler assigns the whole channel resources to the packet call that has the maximum value of the SNR. The station to be served has to belong to the scheduling list [8].

3 Design of proposed scheduling mechanism

In this section, the scheduling mechanism for connections with various QoS requirements is explained. We first define environment requirements for design of the proposed scheduling system and then describe the Fuzzy Interclass scheduler (FIS).

3.1 Environment definition

This paper defines a model of bandwidth requests scheduling for IEEE 802.16d WiMAX systems. There exist N classes of traffic, where each traffic class has its

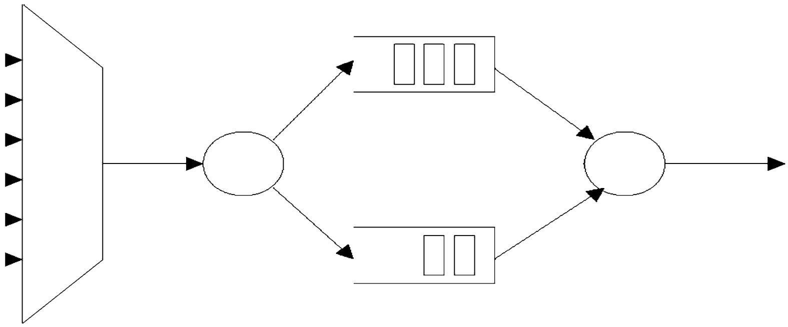


Fig. 1 Scheduling mechanism for multiple traffic classes

own queue q_i; $i = 1 : N$. The bandwidth request of subscribers SS_j with the same class is integrated in same queues q_i. Let q_1 denote the queue for UGS traffic that has the highest priority because of specifications of this class. q_N denotes the queue for best effort traffic, which has no predefined delay and throughput requirements. Then we focus on the remainder of queues q_i; $i = 2 : N - 1$.

All packets in our system have an exponential length except packets related to UGS class; because UGS supports fixed-size data packets. This is typical for internal queues in routers that use a cell switching fabric. The arrival of packets is described by a Poisson process, where the mean arrival rate a_i for each connection c_i is represented by the probability of arriving a packet to c_i. The role of the Fuzzy Interclass Scheduler (FIS) is to decide which queue should be serviced at this time of scheduling. Figure 1 represents the schematic of the scheduling system.

3.2 Fuzzy interclass scheduler (FIS) description

We define the set of state vectors $\mathbf{S}$ for the system, $\mathbf{S} = \{S_i,\ i = 1, 2, \ldots, M\}$; each state S_i, $S_i = (L_1, L_2, \ldots, L_k)$, is produced by K fuzzy linguistic variables selected to describe the system. L_k is represented by a fuzzy term set. There is a set of actions $\mathbf{A}$ possibly chosen by system states, $\mathbf{A} = \{A_j,\ j = 1, 2, \ldots, N\}$. For an input state vector $\mathbf{x}$ containing the K variables, $\mathbf{x} = (x_1, x_2, \ldots, x_K)$, the rule exhibition of FIS for state S_i is

$$\text{if } x \text{ is } S_i,\ \text{then } A_j, \quad 1 \le i \le M \quad \text{and} \quad 1 \le j \le N \tag{1}$$

where A_j is the jth action candidate that is possibly chosen by state S_i. The number of state-action pairs for each state S_i equals the number of the elements in the action set; i.e. each antecedent has N possible consequences. Every fuzzy rule needs to choose an action $\boldsymbol{a}(S_i)$, $\boldsymbol{a}(S_i) = A_j$, from the action candidates set $\mathbf{A}$ by an action-selection policy by means of a Decision Table. To use the M fuzzy rules, the related action $\boldsymbol{a}(\mathbf{x})$ for the input vector $\mathbf{x}$ is expressed by

$$\boldsymbol{a}(x) = \boldsymbol{a}(S_i), \quad \text{if } \alpha_i = \max_{k=1}^{M} \alpha_k \tag{2}$$

where α_i is the truth value of the rule representation of FIS for state S_i. At each timeslot, the scheduler must select a queue q_j with state-action pair $(x, \boldsymbol{a}(x))$.

4 Implementation of fuzzy interclass scheduler (FIS)

We implement the FIS over the environment defined in Sect. 3. In the current section, first some facts of the interclass implementation is shown; then a way for an intra-class mechanism is represented.

4.1 Inter-class implementation

The FIS selects two input variables: HOL packet latency of connection c_i in the head of queue q_{rt}, is related to rtPS class service (dq_{rt}), where packet latency is delay between the reception of a packet and the forwarding of this packet. Throughput of queue q_{nrt} is related to nrtPS class service (tq_{nrt}). Throughput is defined as the ratio of the number of successfully transmitted packets and the number of generated packets. Accordingly, the system state vector **x** containing the two input variables to FIS is defined as

$$x = (dq_{rt}, tq_{nrt}). \tag{3}$$

In numerous experiments we found that five terms for dq_{rt}, and three terms for tq_{nrt} have a better response. Hence, their fuzzy term sets are $T(dq_{rt}) = \{$Low, Low Medium, Medium, Medium High, High$\} = \{$L, LM, M, MH, H$\}$, $T(tq_{nrt}) = \{$Low, Medium, High$\} = \{$L, M, H$\}$. From the fuzzy set theory, the fuzzy rule base forms have dimensions $|T(dq_{rt})| \times |T(tq_{nrt})|$. Decision table for these assumptions is represented in Table 1.

On the other hand, the step-wise action for choosing queue q_i as output, denoted by oq, is selected as the output linguistic variable. Here, two levels of actions $(N = 2)$ are given, and the corresponding fuzzy term set is $T(oq) = \{q_{rt}, q_{nrt}\}$. We generate Table 2 based on comprehensive experiments.

Figure 2 shows the structure of FIS as an implementation of a fuzzy inference system.

We have four steps for choosing output.

Step 1: We define eight parallel nodes. Each node k, $1 \leq k \leq 8$ exhibits a fuzzy term of an input linguistic variable (evidently $|T(dq_{rt})| + |T(tq_{nrt})| = 5 + 3 = 8$), where $k = 1, \ldots, 5$ denotes that node k is the kth term in $T(dq_{rt})$ and $k = 6, 7, 8$ denotes that node k is the $(k-5)$th term in $T(tq_{nrt})$. The node function is defined as

Table 1 Decision table for FIS

		Fuzzy terms for rtPS HOL latency				
		L	LM	M	MH	H
Fuzzy terms for nrtPS throughput	L	$a(1)$	$a(2)$	$a(3)$	$a(4)$	$a(5)$
	M	$a(6)$	$a(7)$	$a(8)$	$a(9)$	$a(10)$
	H	$a(11)$	$a(12)$	$a(13)$	$a(14)$	$a(15)$

Table 2 Loaded action decision table

		Fuzzy terms for rtPS HOL latency				
		L	LM	M	MH	H
Fuzzy terms for nrtPS throughput	L	q_{nrt}	q_{nrt}	q_{nrt}	q_{rt}	q_{rt}
	M	q_{nrt}	q_{nrt}	q_{rt}	q_{rt}	q_{rt}
	H	q_{rt}	q_{rt}	q_{rt}	q_{rt}	q_{rt}

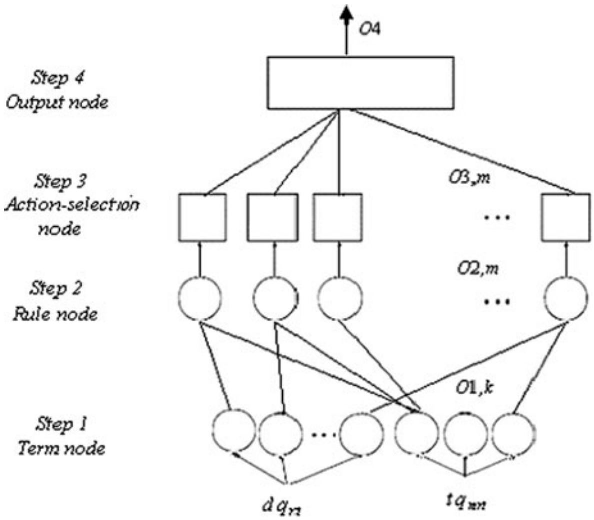


Fig. 2 Structure of FIS

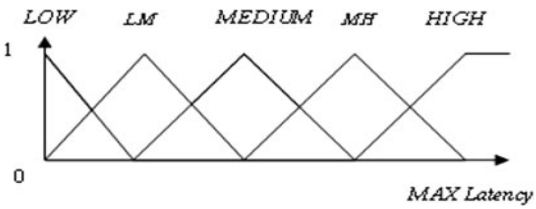


Fig. 3 Membership function for rtPS HOL latency

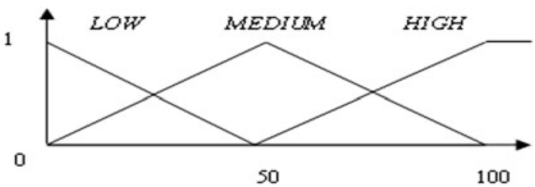


Fig. 4 Membership function for nrtPS throughput

the membership function with triangular terms as presented in Figs. 3 and 4. Thus, for an input variable, the output $O_{1,k}$ is given by its membership function, as shown in Fig. 5.

Step 2: We have 15 nodes. Each node m, $1 \leq m \leq 15$ in this step is a rule node which exhibits the truth value of the mth fuzzy rule; it is a *fuzzy*-AND operator. Here,

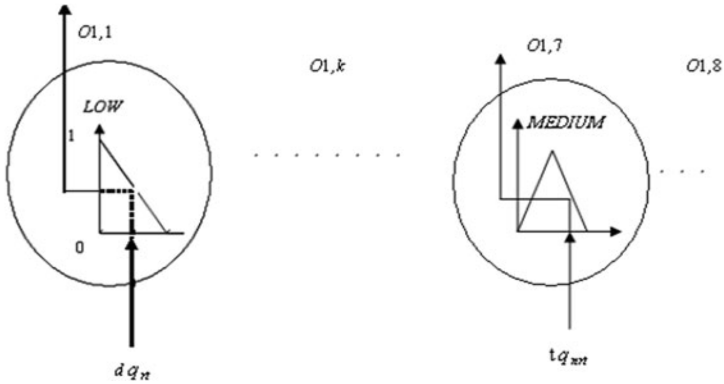
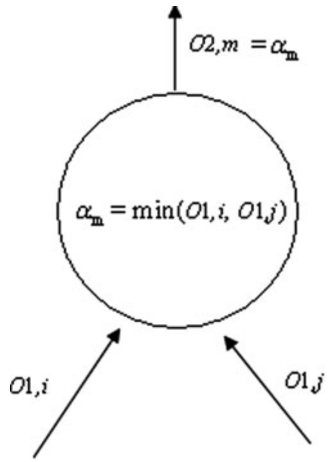


Fig. 5 Term node mechanism

Fig. 6 Rule node mechanism



the minimum value operation is employed as the node function. Since each fuzzy rule has two input linguistic variables, the node output $O_{2,m}$ is the result of operating over two fuzzy membership values corresponding to the inputs. Therefore, $O_{2,m}$ is given by

$$O_{2,m} = \min\{O_{1,L}\}, \quad \forall L \in P_m, \tag{4}$$

where $P_m = \{L|$ all Ls that are the pre-condition nodes of the mth fuzzy rule$\}$. Figure 6 shows the behavior of each node in this step.

Step 3: Every node m, $1 \le m \le 15$, in this step is an action-selection node. Action-selection policy is based on the decision table for selecting action candidates (q_{rt}, q_{nrt}); the node needs to choose an appropriate action as shown in Fig. 7. This step assigns action $\boldsymbol{a}(m)$ for each node from Table 2. q_{rt} denotes rtPS queue and q_{nrt} denotes nrtPS queue. Each node sends one output $O_{3,m}$ to the node in step 4. The

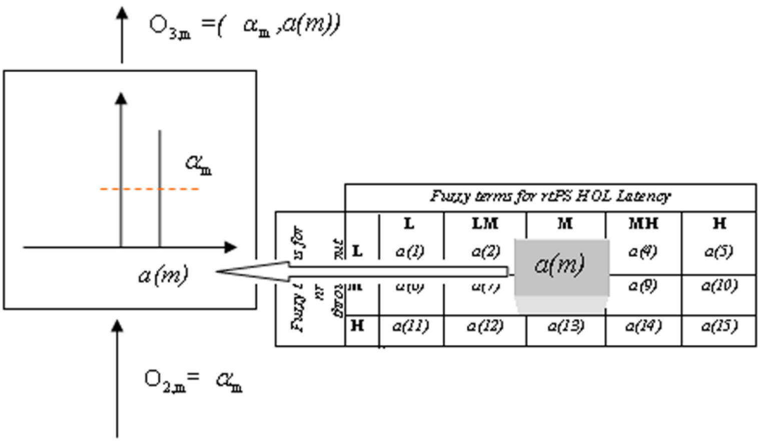
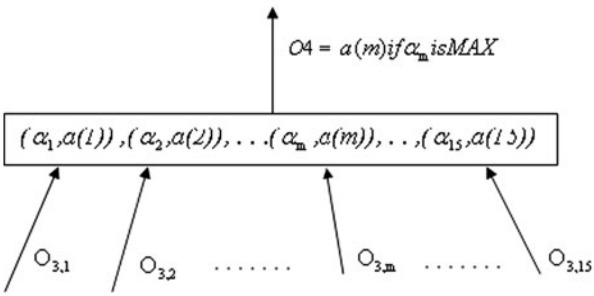


Fig. 7 Action-selection node mechanism

Fig. 8 Output node mechanism



output is represented by

$$O_{3,m} = \big(O_{2,m}, a(m)\big). \tag{5}$$

Step 4: This step has one output node O_4, where the maximum value method represented by (6) is applied for defuzzification of output of FIS, and the crisp value denotes the chosen action as shown in Fig. 8.

$$O_4 = O_{3,m}(2), \quad \text{if } O_{3,m}(1) = \max_{k=1}^{15}\big(O_{3,k}(1)\big). \tag{6}$$

4.2 Intra-class mechanism

For intra-class in rtPS queue, we sort connections with the following algorithm:

1) *FOR all Connections* c_i

IF SNR of c_{i+1} is greater than SNR of c_i *and HOL latency for* c_i *is not in {MH, H}*

then replace c_i *with* c_{i+1} *in rtPS queue*

2) *FOR all Connections* c_i

IF HOL Deadline for c_{i+1} *is less than HOL Deadline for* c_i *and HOL latency for* c_{i+1} *is in*

{MH, H}

then replace c_i *with* c_{i+1} *in rtPS queue.*

For intra-class in the nrtPS queue, we use a maximum signal to interference ratio (mSIR) as presented in [6].

5 Simulation results

For testing the performance of the mechanism proposed, the introduced FIS is implemented in the Network Simulator (NS-2) [9] and WiMAX module [8] that is based on the WiMAX NIST module [10]. The main parameters of the simulation are represented in Table 3. Effects of these parameters are similar over results of all scheduling algorithms. Moreover, producers of this WiMAX module have used these values for testing the performance of their simulator.

We have considered 60 ms for rtPS maximum latency. Suppose that current frame number is f_i, consequently the deadline for all requests that are created in f_i is 60 ms. Also the deadline for requests that have remained with no response from f_{i-1} is (60-frame duration) ms, for requests that have been remained from f_{i-2} it is (60 − 2*(frame duration)) ms and so on. Therefore, the maximum latency has a variable behavior.

In this section, we compare five scheduling algorithms: the NIST_RR, mSIR, RR, TRS + RR, and TRS + mSIR schedulers with the proposed method.

5.1 Performance of FIS for rtPS class

To study the behavior of the FIS for a rtPS class, we have used five UGS SSs; each SS generates a constant bit rate (CBR) traffic with a rate of 160 Kbit/s. Also we have two nrtPS SSs that generate FTP traffic and nine rtPS SSs. Figure 9 shows throughput of the rtPS connections as a function of the rtPS traffic load submitted to the network.

Table 3 Main parameters of the simulation

Parameter	Value
Frequency band	5 MHz
Propagation model	Two Ray Ground
Antenna model	Omni antenna
Antenna height	1.5 m
Transmit power	0.25
Receive power threshold	205e-12
Link adaptation	Enabled
Frame duration	20 ms
Cyclic prefix (CP)	0.25
Simulation duration	100 s

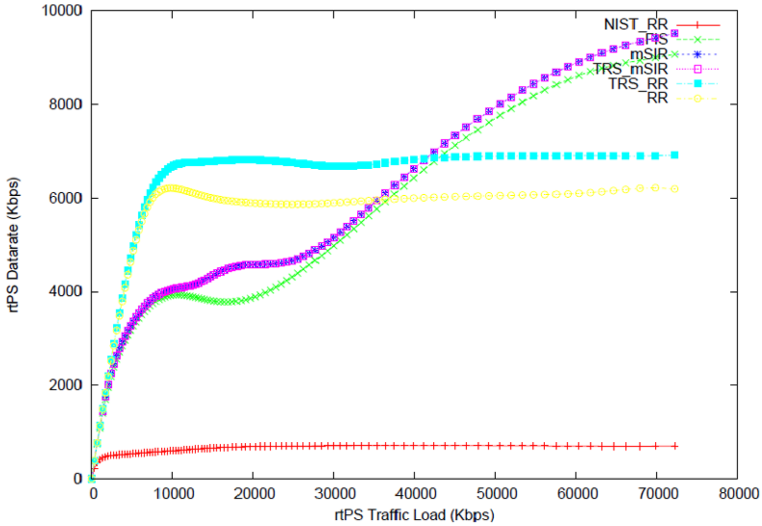


Fig. 9 rtPS throughput versus offered rtPS traffic load

Figure 9 shows that the FIS with mSIR and TRS + mSIR perform much better than the other schedulers with a maximum throughput of approximately 9 Mbit/s. These schedulers favor SSs having the highest SNR values and then the most efficient Modulation Coding schemes (MCSs).

The mSIR and TRS + mSIR are better than FIS in data rate, because in those schedulers, rtPS requests have higher priority than the nrtPS class requests, and in the intra-class mechanism, users with high SNR have the high priority, independent of other delays and deadlines.

Figure 10 shows that the FIS has a very good behavior in the packets' mean latency, because this scheduler controls rtPS class latency in both inter- and intra-class mechanism by considering SNR values of the subscribers.

TRS + RR has good behavior than the RR scheduler because the channel quality of different SSs is not taken into consideration in RR.

NIST_RR has a low efficiency, because this scheduler allocates all the symbols to SS even if it has no data to send.

5.2 Performance of FIS for nrtPS class

To study the behavior of FIS for the nrtPS class we used three nrtPS SSs that generate FTP traffic and nine rtPS SSs that generate UDP traffic.

Figures 11 and 12 show that TRS + RR has weak performances in both latency and throughput for the nrtPS class. NIST_RR provides the same nrtPS throughput independent of the offered traffic load, because NIST_RR is applied to all QoS classes.

FIS has the best performance in both latency and throughput, because it controls the behavior of system and QoS requirements to decrease starvation of this class connections.

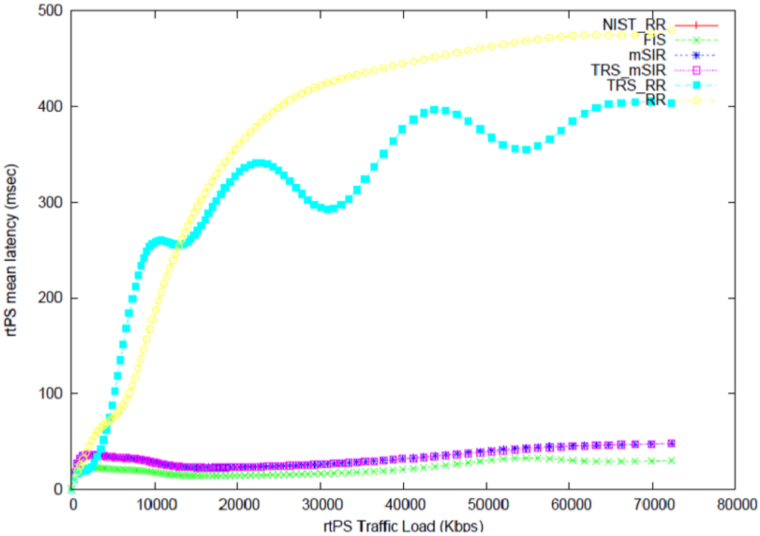


Fig. 10 rtPS latency versus offered rtPS traffic load

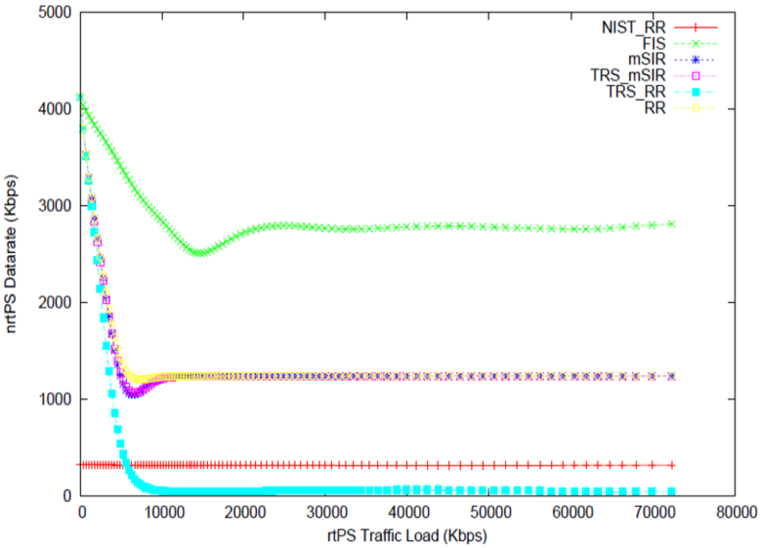


Fig. 11 nrtPS throughput versus offered rtPS traffic load

6 Conclusions

In this paper, a scheduling system based on fuzzy logic is proposed for combination of real-time and non-real-time polling services in WiMAX networks.

The behavior of some scheduling algorithms and the FIS in terms of latency and throughput QoS parameters were compared. FIS with mSIR and TRS + mSIR have

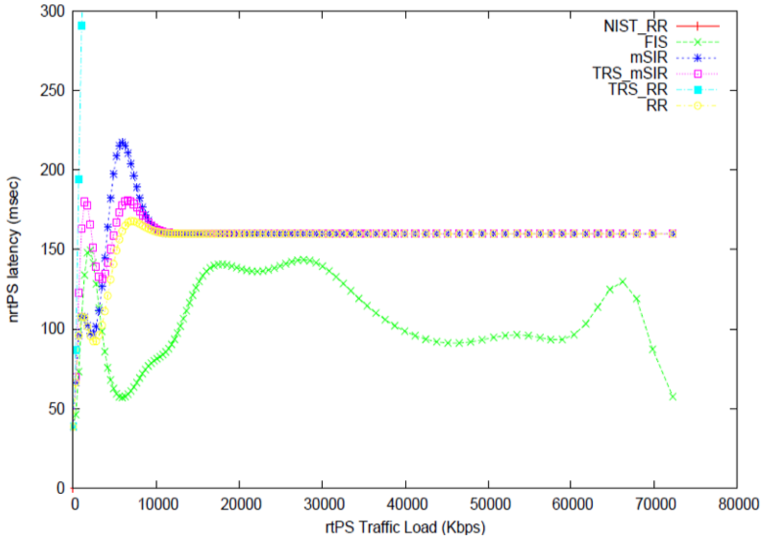


Fig. 12 nrtPS latency versus offered rtPS traffic load

the better results for the rtPS class but FIS has the best behavior in delay and throughput parameters for both rtPS and nrtPS classes.

Simulation results show that the proposed Scheduler finds efficient solutions for nrtPS and rtPS traffics and increases fairness in dividing bandwidth between different applications.

For future work, we will use our proposed method to build up a flexible and intelligent system based on neuro-fuzzy systems. In this system we will replace term nodes and/or action-selection nodes with neurons and will train them to minimize packet latency and maximize system throughput for improving QoS and increasing system performance.

Using genetic algorithms for tuning and finding optimal configurations of the membership functions that we represented in Sect. 4.1 may be a future topic of research.

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