The Forward Link Performance Study of the WiMAX System Under Different Schedulers

Leandro Bento Sena Marques & Shusaburo Motoyama

Abstract— **The forward link performance study of the WiMAX system is presented in this paper. The study is carried out using HTTP traffic model and several different schedulers. The average packet delay, the throughput and packet loss percentage are analyzed through simulation in function of traffic load. The schedulers adopted in this study are Max C/I (Maximum Carrier Interference), PF (Proportional Fair) and Pr/PF (Priority Proportional Fair). The results show that standardized IEEE 802.16e system allows data transmission at high bits rates. Moreover, it was showed that depending on the chosen scheduler, it is possible to assure the QoS for users with high and low priority in WiMAX system.**

Index Terms— **WiMAX System and schedulers PF, Max C/I, Pr/PF.**

I. Introduction

In last years, the rapid growth of new services based on multimedia applications, such as VoIP (Voice over IP), video conference, VoD (Video on Demand) has demanded higher bandwidth and new technologies for wireless access network. One of the technologies that has been created is the IEEE 802.16[1] standard, also known as Worldwide interoperability for Microwave Access (WiMAX).

The IEEE 802.16 standard provides high data rates, pre-defined quality of Service (QoS) framework and low cost in comparison with others technologies based on fixed cable such as Digital Subscriber Line (DSL). Moreover, this standard can be used to connect home networks and business LANs to the Internet[3]. The current version of IEEE 802.16e[2] added new features and necessary attributes to support mobile applications.

Many papers have been published with focus on performance evaluation of WiMAX system [3]-[8]. In [4], it is evaluated 802.16-2004 standard that is intended to fixed broadband wireless access. The main result of this paper is that system capacity is strongly dependent on its configuration, e.g. channel size, frame duration, coding rate, etc.

In another study presented in [5], the IEEE 802.16e system is compared to 3GPP UMTS HSDPA by using simulations. The simulation results indicate that the 802.16e system using 70/30 Time Division Duplex (TDD) frame provides approximately the same downlink system throughput performance as HSDPA with approximately 40%-50% higher spectral efficiency. However, control channel overhead and uplink capacity limitation remain as open issues. Furthermore, it is considered only proportional fair (PF) scheduler as alternative scheduler to improve QoS of system.

A simulation study of the IEEE 802.16 MAC protocol operated with the WirelessMAN-OFDM air interface and with full-duplex stations is presented in [6]. The results show that the performance of the system (downlink/uplink), in terms of throughput and delay, depends on several factors. These include the frame duration, the mechanisms for requesting uplink bandwidth, and the offered load partitioning, i.e., the way traffic is distributed among SSs, connections within each Subscriber Stations (SS), and traffic sources within each connection. The schedulers adopted in the study are: Deficit Round Robin (DRR) as the downlink scheduler and Weighted Round Robin (WRR) for uplink scheduler.

The works presented in [7]-[8] emphasize improvements in uplink schedulers and QoS architecture of WiMAX system. In [3] it is proposed a queue-aware uplink bandwidth allocation scheme which is able to adjust the allocated bandwidth adaptively according to the queue state. However, in current context of IP networks results are inaccurate due to use of Poisson traffic sources during computer simulations.

In this paper, the IEEE 802.16e system is evaluated through the queuing system considering Hypertext Transfer Protocol (HTTP) traffic model proposed in [9]. The system throughput, the average delay of the packets and loss percentage are studied in function of the traffic load. The performance of the forward link is studied by using packet schedulers such as Proportional Fair (PF), Maximum Carrier Interference (Max C/I) and Priority Proportional Fair proposed (Pr/PF) in [10]. The study is carried out through simulation using Matlab software tool.

In Section II a brief description of the WiMAX system is presented. The simulation model is described in Section III. The packet schedulers PF, Max C/I and Pr/PF are described in Section IV. Scenario evaluated in this paper is presented in Section V. In Section VI, the simulation results and its analyses are presented. Finally, the conclusions are exhibited in Section VII.

II. WiMAX

In the IEEE 802.16e architecture, two kinds of stations are defined: subscriber stations (SS) and a base station (BS). The BS controls all communication in the network, i.e., there is no peer-to peer communication directly between the SSs. WiMAX technology supports two types of connection modes: PMP (Point to Multipoint) and Mesh which application is

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optional. The PMP represents the classical cellular model when a SS is connected directly to the BS. In this paper, only PMP mode is considered.

The communication path between SS and BS has two directions: uplink (UL - from SS to BS) and downlink (DL - from BS to SS). The DL indicates direction of data flow from BS to SS , and UL indicates the data flow in opposite direction from SS to BS. The air interface is based on Orthogonal Frequency Division Multiplexing (OFDM) which is a multiplexing technique that subdivides the bandwidth into multiple frequency sub-carriers as shown in Fig. 1. In an OFDM system, the input data stream is divided into several parallel sub-streams of reduced data rate (thus increased symbol duration) and each sub-stream is modulated and transmitted on a separate orthogonal sub-carrier. The OFDM sub-carrier structure consists of three types of sub-carriers: data sub-carriers for data transmission, pilot sub-carriers for estimation and synchronization purposes and null sub-carriers used for guard bands and DC carriers.

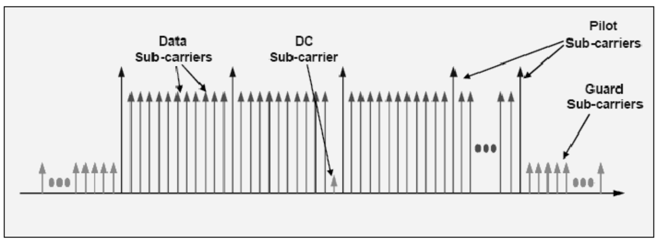

Fig. 1. OFDM Sub-Carrier Structure[5].

The resources, in a OFDM system, are available in the time domain by means of OFDM symbols and in the frequency domain by means of sub-carriers. The time and frequency resources can be organized into sub-channels for allocation to individual users. Orthogonal Frequency Division Multiple Access (OFDMA) is a multiple-access/multiplexing scheme that provides multiplexing operation of data streams from multiple users onto the downlink sub-channels and uplink sub-channels [13].

The minimum frequency-time resource unit of sub-channelization is one slot, which is composed of 48 data tones (sub-carriers). Frequency-specific sub-channelisation is supported via the called Band Adaptive Modulation and Coding (AMC) mode, which permits subchannel construction through physically adjacent subcarrier allocation (four different Band AMC subchannel dimensions are currently specified). Thus the allowed combinations are [(6 bins, 1 symbol), (3 bins, 2 symbols), (2 bins, 3 symbols), (1 bin, 6 symbols)]. A bin consists of 9 contiguous sub-carriers, with 8 assigned for data and one assigned for a pilot. In this paper, it was considered only 2 bins and 3 symbols for simplifying simulations.

In WiMAX, two types of duplexing method are specified, TDD and FDD. This paper is concerned with TDD duplex method where every frame is divided into DL and UL subframes. The frame structure for a TDD implementation is shown in the Fig. 2. Each frame is divided into DL and UL subframes separated by Transmit/Receive and Receive/Transmit Transition Gaps (TTG and RTG, respectively) to prevent DL and UL transmission collisions. In OFDM PHY every burst (either DL or UL), consists of integer number of OFDM symbols.

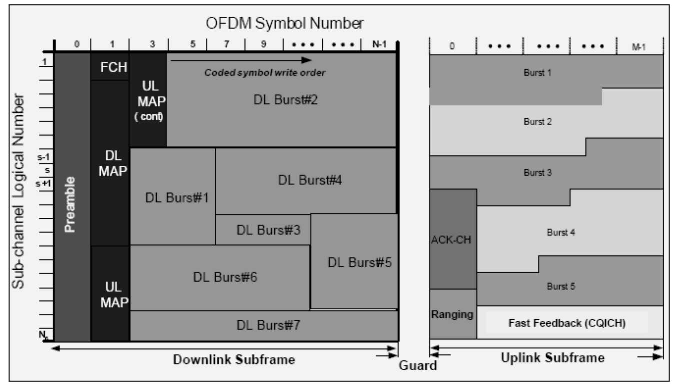

Fig. 2. WiMAX OFDMA Frame Structure[5].

The BS dynamically determines the duration of these subframes. SSs and BS have to be synchronized and transmit data into predetermined slot (SL). Since all SSs are synchronized with the BS clock, the BS controller can transmit data in each slot that will arrive at a particular SS. SSs send requests in the UL to BS. In the downlink, the BS uses a combination of acknowledgement (ACK) and grant (GR) slots to acknowledge requests from SSs and to grant access to data slots.

The following Table I provides a summary of the theoretical peak data rates for various DL/UL ratios assuming a 10 MHz channel bandwidth, 5 ms frame duration with 44 OFDM data symbols (from 48 total OFDM symbols) [13]. The data rates supported by forward link can vary from 1.06 Mbps up to 31.68 Mbps by a sector of a cell. One of three schemes of modulation QPSK, 16QAM and 64 QAM is used depending on data rate.

TABELA I
MODULATION TYPE PER DATA RATE

Modulation	DL(Mbps)	UL(Mbps)
QPSK	**1.06**	0.78
QPSK	**1.58**	1.18
QPSK	**3.17**	2.35
QPSK	**6.34**	4.70
QPSK	**9.50**	7.06
16QAM	**12.67**	9.41
16QAM	**19.01**	14.11
64QAM	**19.01**	14.11
64QAM	**25.34**	18.82
64QAM	**28.51**	21.17
64QAM	**31.68**	23.52

In the WiMAX standard four QoS services are defined: Unsolicited Grant Service (UGS); Real-Time Polling Service (rtPS); Non-Real-Time Polling Service (nrtPS) and Best Effort (BE) service. UGS service can be used for constant bit-rate (CBR) for service flows such as T1/E1. Real-time Polling Services (rtPS) can be used for rt variable bit rate (VBR) service flows such as MPEG video. Non-real-time Polling Service (nrtPS) can be used for non-real-time service flows with better performance than best effort service such as bandwidth-intensive file transfer. At last, for BE service there is no resource allocation.

III. Simulation Model

In Fig. 3a it is shown the part of WiMAX system that this paper is concerned. The packets generated in core network are sent for a BS buffer. In this point they are shared in four queues (UGS, rtPS, nrtPS and BE) according to packet priority and stay waiting until will be served. The IP packets (1500 bytes and 576 bytes) may be eventually segmented to adjust in rates that will be sent. Thus, the forward link simulation model of WiMAX system can be represented as shown in Fig. 3b.

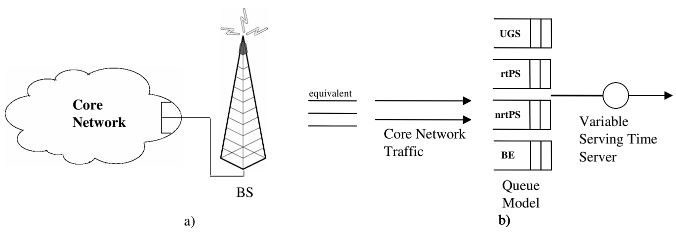

Fig. 3. WiMAX Simulation Model.

The following assumptions are adopted. The IP packets generated by HTTP sources proposed in [9] are classified according to four types of service flows defined in WiMAX QoS architecture, i.e, UGS, rtPS, nrtPS and BE. These flows are discriminated in appropriate queue by scheduler. The scheduler uses PF[11], Max C/I[12] or Pr/PF algorithm proposed in [10]. The buffer of each queue has finite size. The queue sizes are detailed in Section V. The slot comprises 48 data sub-carriers and 24 pilot sub-carriers in 3 OFDM symbols according to [13]. Thus, it is assumed that there are total of 16 SLs in a WiMAX frame which are divided into a DL/UL rate of 3:1 for 2x2 MIMO (Multiple-Input Multiple-Output), i.e., 1 SL for overhead, 3 SLs for UL channel and 12 SLs for DL channel.

In Table II it is shown the rate distribution adopted for the simulation. The adopted distribution is hypothetical and it is assumed the average rate is concentrated at 12.67 Mbps.

TABELA II
Probability Distribution Per Data Rate

DL(Mbps)	Probability
1.06	3%
1.58	4%
3.17	6%
6.34	10%
9.50	12%
12.67	17%
19.01	16%
19.01	14%
25.34	9%
28.51	5%
31.68	4%

IV. Data Schedulers

Since the IEEE 802.16e standard does not specify the scheduler for downlink [2], the adopted data schedulers in this study are presented. Thus, the following data schedulers are used: Max C/I[12] (Maximum Carrier Interference), PF[11] (Proportional Fair) and Pr/PF[10] (Priority Proportional Fair).

A. Proportional Fair (PF)

The PF schedules the users according to the ratio between their instantaneous achievable data rate and their average served data rate. This results in all users having equal probability of being served even though they may experience very different average channel quality. This scheme provides a good balance between the system throughput and fairness. In equation 1, the acronym P_i denotes the user priority, $R_i(t)$ is the instantaneous data rate experienced by user i if it is served by the packet scheduler, and $\lambda_i(t)$ is the user throughput

$$P_i = \frac{R_i(t)}{\lambda_i(t)}, i = 1, ..., N \tag{1}$$

B. Maximum Carrier Interference (Max C/I)

The maximum C/I scheme schedules the users with the highest C/I during the current slot. This naturally leads to the highest system throughput since the served users are the ones with the best channel. However, this scheme makes no effort to maintain any kind of fairness among users. In fact, users at the cell edge will be largely penalized by experiencing excessive service delays and significant outage.

C. Priority Proportional Fair (Pr/PF)

The hybrid scheduler Pr/PF combines the priority scheduler with PF. In this scheme, packets with high priority from services flows UGS and rtPS are first served while packets from services nrtPS and BE are served in accordance with PF scheduler. The Fig. 4 illustrates Pr/PF scheduler. In this manner, this scheduler contemplates users that need differentiated serving and also users with low restrictions of QoS that tolerate delays during services.

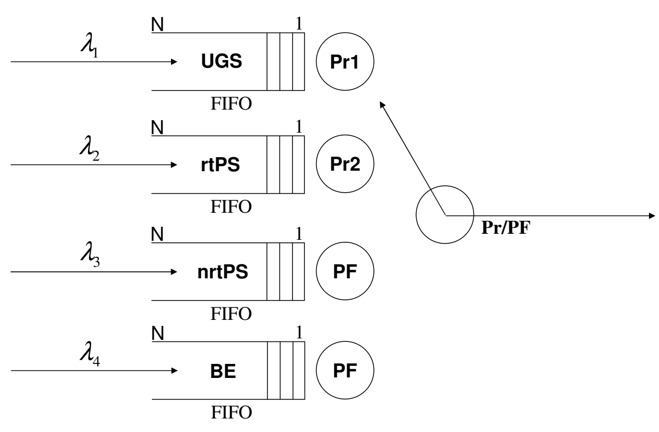

Fig. 4. Pr/PF Data Scheduler

V. Scenario Evaluated

The evaluated scenario consists in increasing the number of HTTP sources varying from 152 (20% link utilization) up to 675 (80% link utilization) as exhibited Table III. Several schedulers are used in order to evaluate which one among PF, Max C/I or Pr/PF guarantees the best QoS for SSs. For Pr/PF scheduler the UGS service has highest priority, the rtPS service has second highest priority and nrtPS and BE sources are served according to PF scheduler. The behavior of WiMAX system is analyzed through two finite queues: one has a small length of buffer (10 packets) and another has large length buffer (100 packets). The probability distribution, traffic proportion and buffer size adopted in this paper are shown in Table IV.

TABELA III
Scenario

Link Utilization	HTTP Sources
20%	152
40%	310
60%	470
80%	675

TABELA IV
Probability Distribution vs Buffer Size

Priority	Proportion	Buffer1	Buffer2
UGS	10%	1	10
rtPS	25%	3	25
nrtPS	30%	3	30
BE	35%	3	35
Total	100%	10	100

The performance measurements considered in this study are: the average packet delay, the throughput, the loss percentage, all in function of link utilization.

VI. Results Analysis

The results obtained through simulations are organized and presented in graphics. In these graphics the acronym BX represents finite buffer 1 or 2. The buffer 1 is illustrated as continuous line and buffer 2 as dashed line. Moreover, acronyms PFX, MaxCIX and Pr/PFX refer to PF, Max C/I and Pr/PF schedulers, and X represents level of priority. The level 1 is the highest priority, i.e, traffic generated by UGS service and the level 4 is the lowest priority for BE service and so on. The average standard deviation was 3.32% and 95% confidence interval was 2.06% of the average value.

The throughputs for Pr1 and Pr4 users have the same behavior for all schedulers as are shown in Figs. 5 and 6. These throughputs are normally higher when are used buffer 2 with large total capacity of 100 IP packets and lower when are used buffer 1 with small total capacity of 10 IP packets. In relation to the throughput behavior the schedulers PF, Max C/I and Pr/PF present little influence for traffic with priority 1 or 4. However, it is possible to note a little advantage of scheduler Pr/PF1 for users with high priority in Fig. 5 due to absolute priority. In another Fig. 6 can be observed the best performance of PF4 users because of PF scheduler directs more system resources to users with low priority. The others users Pr2 and Pr3 present similar performances.

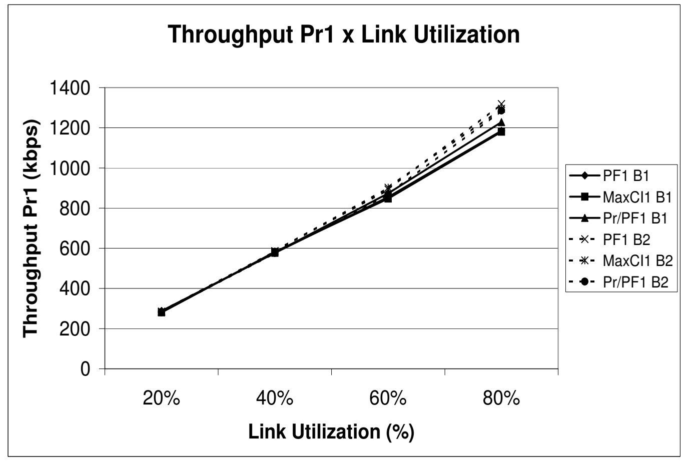

Fig. 5. Throughput Pr1 in Function of Link Utilization.

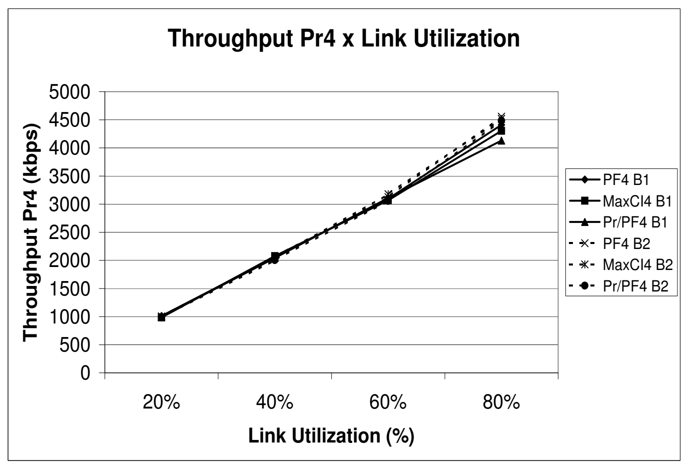

Fig. 6. Throughput Pr4 in Function of Link Utilization.

Fig. 7 illustrates the average delay for Pr1 users in function of link utilization varying from 20% up to 80% and using HTTP sources. As observed in this figure delays obtained using Pr/PF1 scheduler are very small and independent of buffer scheme adopted due to absolute priority of Pr1 users. The scheduler MaxCI1 presents intermediate performance with delays varying from 0,16 ms up to 1,9 ms. The scheduler PF1 has the worst performance with maximum delays of 2,5 ms in reason of scheduler tries to maintain user throughput fairness.

In the Fig. 8 is presented the average packet delay for Pr2 users in function of link utilization. The behaviour of data curves is similar to Fig. 8. However, due to intermediate priority of Pr2 users the average delays for all schedulers are increased approximately 0.5 ms in relation to Pr1 users. The best performance is associated with data scheduler Pr/PF2

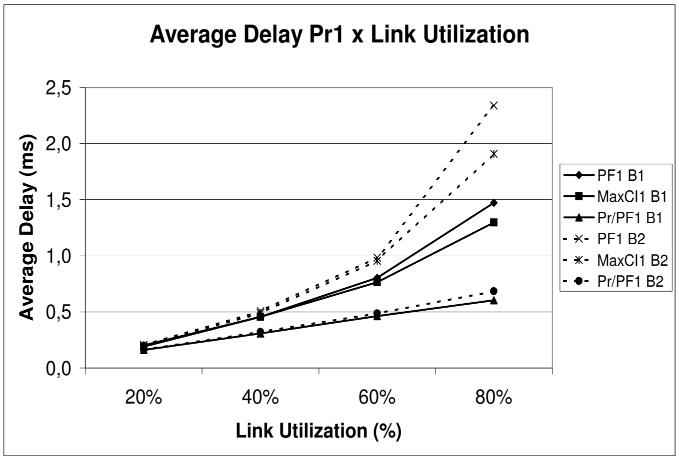

Fig. 7. Average Packet Delay Pr1 in Function of Link Utilization.

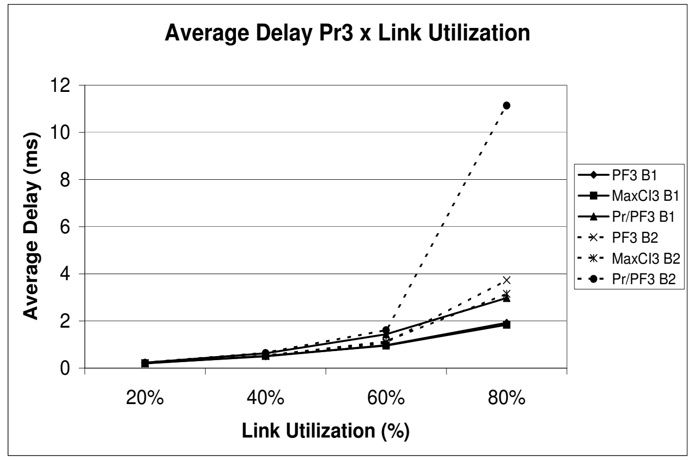

Fig. 9. Average Packet Delay Pr3 in Function of Link Utilization.

independent of buffer size selected varying from 0.2 ms up to 1 ms. For others schedulers when it is used buffer 1 the average delay is reduced with maximum of 2 ms in the worst case.

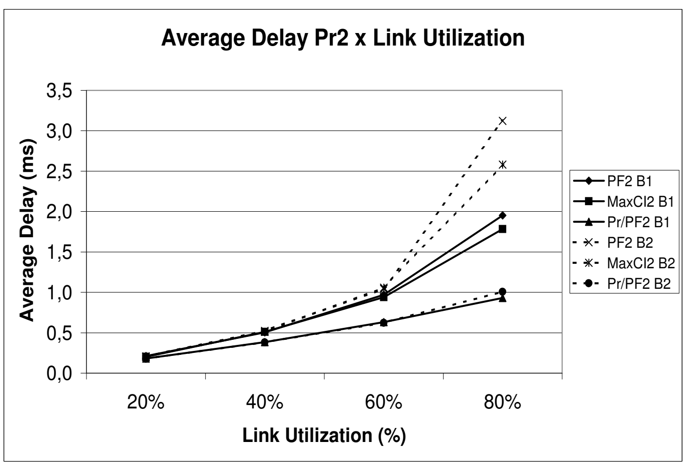

Fig. 8. Average Packet Delay Pr2 in Function of Link Utilization.

The average packet delay of Pr3 users in function of link utilization is shown in the Fig. 9. The most of data schedulers evaluated present average delays lower than 4 ms for both buffer sizes. However, there is an exception in case of scheduler Pr/PF3 with buffer 2 from link utilization of 60% when occurs a saturation of WiMAX system due to excess of low priority users. The scheduler Pr/PF3 presents the worst performance even though it is considered buffer size 1 with average delays ranging from 0.2 ms up to 2.98 ms. The best results are obtained by schedulers MaxCI and PF with maximum average delay of 3.74 ms.

In Fig. 10, the average delay of Pr4 users in function of link utilization varying from 20% up to 80% using HTTP sources is shown. In this case, scheduler Pr/PF4 has the worst delay among schedulers evaluated with average delays varying from 0,2 ms up to 12 ms for buffer 2. In case of buffer 1, average delay are reduced to range 0,2 ms up to 2,85 ms. However, this reduction is associated with high loss percentage. In relation to others schedulers PF4 and MaxCI4, the results show tolerant delay varying up to 4 ms in worst case.

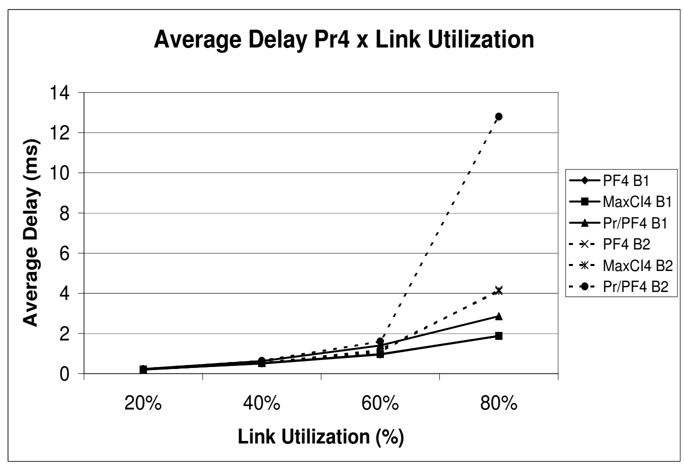

Fig. 10. Average Packet Delay Pr4 in Function of Link Utilization.

The loss percentage of HTTP packets for Pr1 users in function of WiMAX system utilization is shown in Fig. 11. It can be observed once more that, the Pr/PF1 scheduler obtains the lowest loss percentage of HTTP packets during simulation because of high priority of Pr1 users. Others schedulers PF1 and MaxCI1 have maximum loss percentage of 1% in worst case. In case of loss percentage of buffer 2, the losses are negligible because of large capacity buffer with 100 packets IP.

In the Fig. 12 is exhibited loss percentage of Pr2 users in function of link utilization. The highest loss percentages are obtained by scheduler MaxCI2 B1 varying from 0% up to 0.87% during computer simulations. The scheduler PF2 B1 presents intermediate performance with maximum of 0.57% of loss percentage in worst case because of good distribution of WiMAX system resources among their users. The best results are verified by scheduler Pr/PF2 as a result of absolute priority of Pr2 users ranging from 0% up to 0.08%. For others

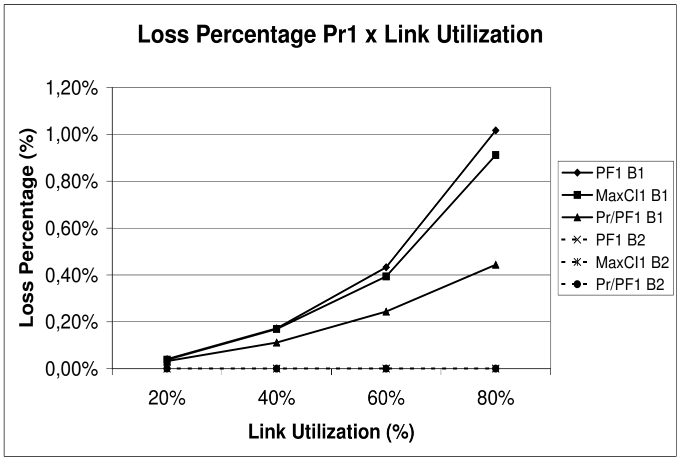

Fig. 11. Loss Percentage Pr1 in Function of Link Utilization.

cases when it is adopted buffer size 2 the loss percentage is negligible.

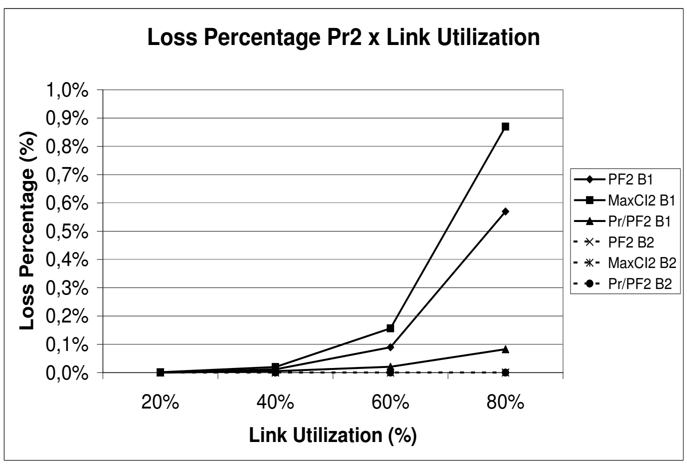

Fig. 12. Loss Percentage Pr2 in Function of Link Utilization.

The loss percentage Pr3 in function of link utilization is exhibited in the Fig. 13. In this case due to low priority users and small buffer size the scheduler Pr/PF3 B1 presents the highest loss percentage among data schedulers evaluated. The schedulers PF3 B1 and MaxCI3 B1 present similar performances with maximum of 0.92% for a link utilization of 80%. In case of buffer 2 the loss percentage for all schedulers were reduced significantly as a result of large buffer size. However, the scheduler Pr/PF3 B2 presents a little loss percentage of 0.15% for link utilization of 80%.

Finally, Fig. 14 exhibits loss percentage of HTTP packets for Pr4 users in function of link utilization. It is clear the high loss of Pr/PF4 scheduler mainly because of lower priority users. The loss is as high as 3% of packets for a link utilization of 80%. The PF4 and MaxCI4 schedulers present small packet losses with a little advantage of PF4.

VII. Conclusions

The forward link performance of the WiMAX system was evaluated by simulation considering traffic model of HTTP and

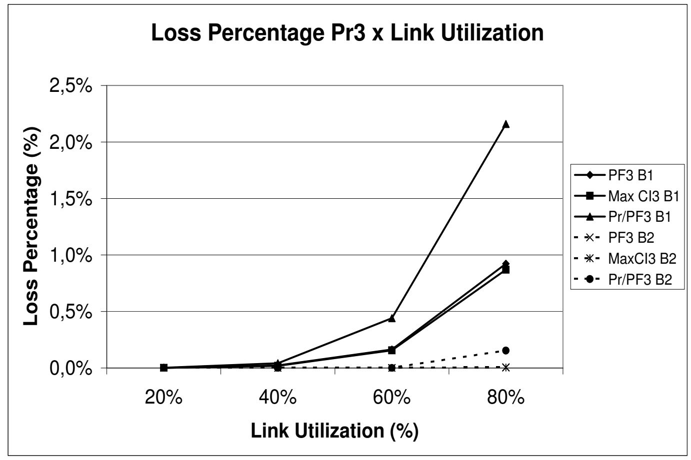

Fig. 13. Loss Percentage Pr3 in Function of Link Utilization.

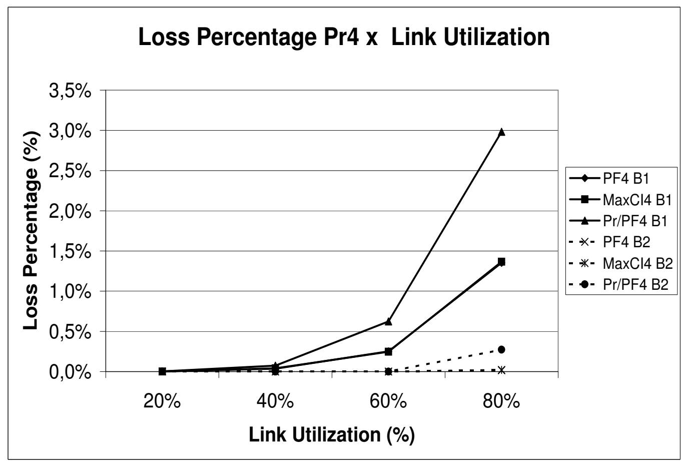

Fig. 14. Loss Percentage Pr4 in Function of Link Utilization.

various types of schedulers such as PF, Max C/I and Pr/PF. The throughput, average delay, loss percentage were studied in function of link utilization.

The results demonstrated that for packet delay and packet loss the Pr/PF scheduler is the most suitable for QoS assurance of WiMAX system with different types of services (UGS, rtPS, nrtPS and BE) because it guarantees small delays and low packet loss for higher priority users and moderate QoS for lower priority users. On the other hand, PF scheduler presented a fair link utilization but it is not appropriate for QoS assurance of different types of service. The same conclusion can be considered for Max C/I scheduler that only maximizes the link utilization. Moreover, the increase of buffer size demonstrated to be a good strategy for reducing loss percentages in the WiMAX system.

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