Dziyauddin, R., Doufexi, A., & Kaleshi, D. (2010). Performance evaluation of MIMO downlink WiMAX for different schedulers. In *6th Conference on Wireless Advanced (WiAD) 2010, London, UK* (pp. 1 - 6). Institute of Electrical and Electronics Engineers (IEEE). https://doi.org/10.1109/WIAD.2010.5544946

Performance Evaluation of MIMO Downlink WiMAX for Different Schedulers

Rudzidatul Akmam Dziyauddin*, Angela Doufexi, Dritan Kaleshi
Centre of Communication Research, Department of Electrical Engineering
University of Bristol, UK
{Rudzi.Dziyauddin, A.Doufexi, Dritan.Kaleshi}@bristol.ac.uk

Abstract—**WiMAX performance evaluation considering different scheduling techniques has received considerable attention by WiMAX researchers and also WiMAX operators. The standard does not define MAC scheduling although it affects the overall QoS performance of users as well as the achievable total cell goodput. The primary goal of this paper is to compare the performance of maximum total goodput including the average delay for UGS (Unsolicited Grant Service) users employing channel-aware and queue-aware downlink schedulers for a group of users. The paper initially considers the goodput behaviour and its peak across different modulation and coding schemes for SISO and MIMO (both Space Time Block Code (STBC) and Spatial Multiplexing (SM)) connections for a single user. The achievable maximum goodput is shown to be between 94.5% and 97.0% of the theoretical data rates. The analysis is then expanded to multiple users considering Proportional Fair (PF) with different observation window, t_c, Greedy and also Weighted Fair Queuing (WFQ) schedulers to serve downlink QoS flows. The PF with a higher t_c = 50K exceptionally outperforms WFQ as well as the PF with a smaller t_c = 500 for a higher number of users and shows a greedy like performance. The channel-aware scheduler generally performs better than the queue-aware scheduler.**

Keywords-WiMAX, Propotional Fair, Greedy, WFQ ,goodput

I. INTRODUCTION

WiMAX can offer high data rates to accommodate a dramatic growth in customer demand. Two primary standards, IEEE 802.16-2004[1] and IEEE 802.16 e-2005 [2] are established to define PHY and MAC interoperability and are effectively promoted by the WiMAX forum. The key technologies in the standards are scalable OFDMA and advanced antenna technologies, namely beamforming, STBC (Space Time Block Code) and SM (Spatial Multiplexing). The next WiMAX Release 2.0 (WiMAX 2) offers new capabilities enhanced spectral efficiency anticipating to double peak data rates as well as to increase average and cell-edge end user performance [3].

SM [4] and STBC [5] MIMO techniques are defined in the standard to achieve higher data rates and improved link reliability. SM can double the goodput compared to SISO for a 2x2 configuration in suitable channel conditions by transmitting separate data streams from each antenna. WiMAX capacity with different set of OFDM parameters are studied in particular for SISO, STBC and SM [6-9]. UGS is one of the defined QoS class types in the IEEE 802.16 standard. It supports VOIP without silence suppression with fixed-size data packets on a periodic basis or Constant Bit Rate (CBR). MAC scheduling studies are conducted to satisfy the QoS requirements such as maximum latency for real-time data, for instance, VOIP.

The key objective of this paper is to study the performance of maximum total goodput including the average delay for UGS users employing channel-aware and queue-aware downlink schedulers. The simulation begins with a straightforward downlink scenario consisting of a BS and a stationary subscriber station (SS) supporting SISO, STBC and SM in a 2x2 MIMO configuration. Our aim is to evaluate the goodput behaviour for a single antenna and multiple antenna techniques. SISO and MIMO PHY link level simulations are initially performed in MATLAB using the Spatial Channel Model [10] and then incorporated in the Qualnet simulator to evaluate realistic user performance. We then explore multiple SSs for various schedulers. In addition, the maximum achievable UGS goodput of a single SS is compared with that of multiple SSs.

This paper is organised as follows: Section II presents the WiMAX PHY and MAC, including a discussion of MAC overheads. Section III describes the QoS downlink schedulers. Section IV shows the simulation model and scenario parameters. Section V discusses the simulation results. Section VI concludes the paper.

II. WIMAX PHY AND MAC

A. WiMAX PHY Data Rates

The raw data rates of OFDMA rely on several parameters such as the bandwidth, FFT size, cyclic prefix, modulation scheme, and coding rate. The raw data rates can be obtained from equation (1):

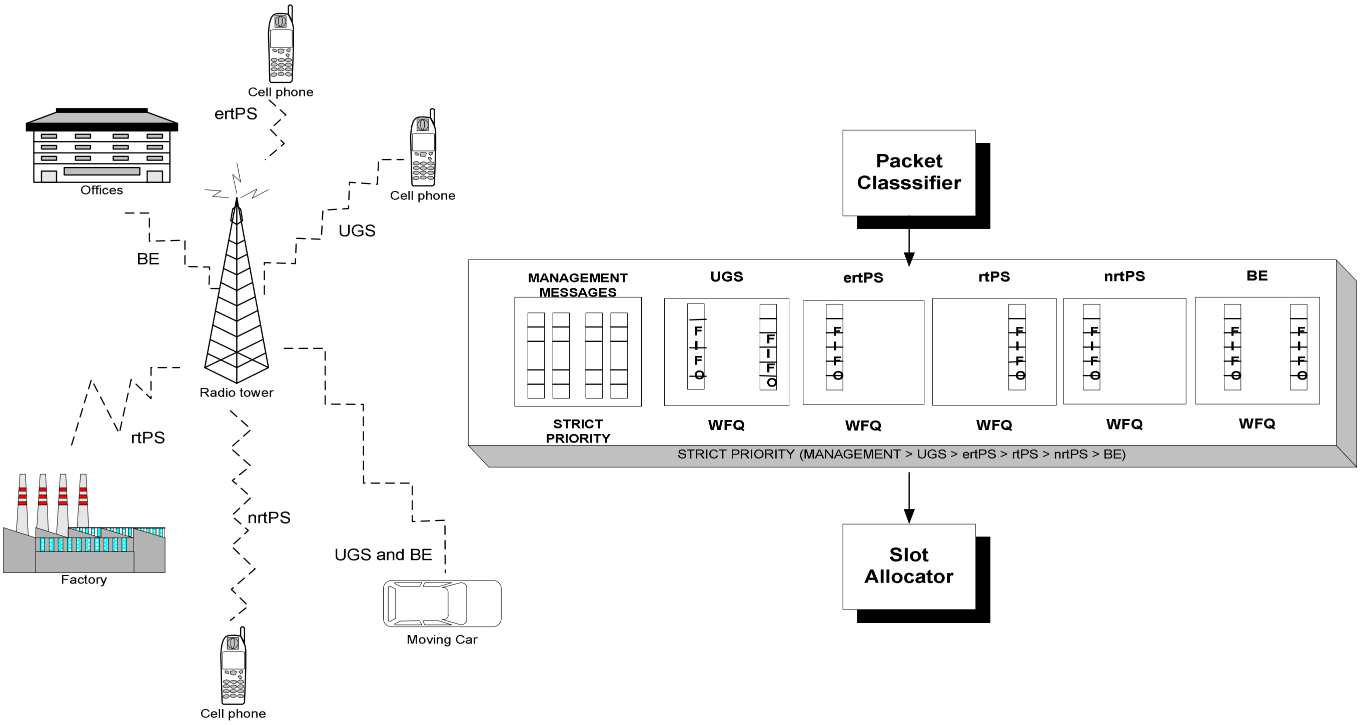
$$R = N * b * c / T \tag{1}$$

where N, b, c and T denote the number of used subcarriers, number of bits per modulation symbol, coding rate and OFDM symbol duration accordingly. The computed symbol duration is 100.8 μs. We calculated the PHY data rates for uplink (UL) and downlink (DL) for SISO, STBC and SM MIMO 2x2 with a DL to UL ratio of 1:1 for a 10 MHz bandwidth. SISO and STBC essentially achieve the same maximum PHY data rates, while SM can double the data rate

---

* Rudzidatul Akmam is also with Universiti Teknologi Malaysia International Campus Kuala Lumpur (UTMKL), Jalan Semarak, 54100 Kuala Lumpur, Malaysia. (e-mail: rudzi@ ic.utm.my).

978-1-4244-7071-6/10/$26.00 © 2010 IEEE



(a) (b)

Figure 1. (a) Seven different QoS service flows in a WiMAX cell, (b) The corresponding packet downlink schedulers employing WFQ for the intra-schedulers and Strict Priority for the inter-scheduler

as shown in Table I. This will be used to calculate the throughput after the MAC layer.

B. IP and MAC Overhead Calculatios for DL Subframe

The impact of MAC overheads in decreasing the WiMAX throughput has been published in [8, 9, and 11]. [11] also discusses MAC overheads using the symbol and frame duration, whereby, the MAC overhead can be summarised as follows:

MAC and PHY overhead in downlink = 4 symbols

Total MAC Overhead = (4 * symbol duration) = 403.2 μs

Overhead over frame size=(0.4032ms/20ms)*100 = 2.016 %

The UDP header and the IPv4 header convey an 8-byte [RFC 768] and a 20-byte [RFC 791] per packet respectively. They contribute to 2.734% overhead over the packet size used for simulations (1024 bytes). Thus, the total percentage of MAC, UDP and IPv4 overheads is close to 5%. Note that for smaller packet sizes, for example, 186 bytes, the total overheads percentage is around 17%.

C. PHY DL Data Rates After Overhead

In order to measure the goodput (application level throughput excluding protocol overheads), the net data rates are calculated. Considering the protocol overheads as in Section II (*B*) with respect to the DL PHY data rates, the calculated data rates are presented in Table I. These maximum net data rates can be used as a benchmark to be compared with the achievable goodput shown in the analysis part.

TABLE I. WIMAX DL PHY DATA RATES AND THEIR DATA RATES AFTER CONSIDERING THE IP AND MAC OVERHEADS FOR SISO, STBC AND SM (PUSC, DL:UL[99:99])

Modulation and Encoding Rate	**SISO and STBC (Mbps)**		**SM (Mbps)**	
	PHY Data Rates	***After IP and MAC Overheads***	***PHY Data Rates***	***After IP and MAC Overheads***
QPSK ½	3.571	3.393	7.142	6.786
QPSK ¾	5.357	5.089	10.714	10.178
16QAM ½	7.143	6.786	14.286	13.572
16QAM ¾	10.714	10.179	21.428	20.358
64QAM ½	10.714	10.176	21.428	20.358
64QAM 2/3	14.286	13.571	28.572	27.142
64QAM ¾	16.071	15.268	32.142	30.536

III. QOS DOWNLINK SCHEDULERS

A. A QoS Scheduler Architecture

Our downlink WiMAX scheduling consists of an inter-scheduler and six intra-schedulers in which five schedulers serve all QoS data type, namely, UGS, ertPS (extended real-time Polling Service), rtPS (real-time Polling Service), nrtPS (non-real-time Polling Service) and BE (Best Effort), and another scheduler handles management messages as depicted in Figure 1. On the other hand, an inter-scheduler serves all these QoS type schedulers as well as the management messages scheduler. We have essentially implemented (i) two channel-aware schedulers, Proportional

Fair and Greedy, and also (ii) a queue-aware scheduler, Weighted Fair Queuing (WFQ) for the intra-schedulers algorithms. They employ a similar scheduler type simultaneously and contain FIFO (First-In-First-Out) queues created based on the service flows. A service flow is a unidirectional MAC transport service for the packets on the uplink and also on the downlink which defines the QoS parameters for the Packet Data Units (PDUs) on a particular connection. Our intra schedulers consider the Head-of-Line (HOL) packet, the packet at the beginning of a queue, to be in service for the DL slots. We employed a Strict Priority scheduler for the inter-scheduler whereby:

management messages > UGS> ertPS > rtPS > nrtPS > BE

to satisfy the stringent QoS requirements accordingly as illustrated in Figure 1.

1) *Weighted Fair Queuing (WFQ)*

WFQ is a variation of Fair Queuing (FQ) presumed from the General Processor Sharing (GPS) algorithm. It assigns a normalized weight of a minimum reserved traffic rate (MRTR) of a QoS flow to each corresponding queue. This weight logically specifies how many bits dequeue when the scheduler services that queue, which effectively controls the percentage of bandwidth allocation for every queue. The scheduling decision is upon the finish number, an estimation of time for a Head-of-Line (HOL) packet in the queue *i* to be served, as a following algorithm:

$$F_i(k,t) = \max\{F_i(k-1,t), R_i(t)\} + P_i(k,t) \tag{2}$$

where $F_i(k,t)$ and $F_i(k-1,t)$ denote the finish number of packet *k* and the last packet before packet *k* on queue *i* at time *t* accordingly, $R_i(t)$ is the round number, an accumulative number of bits that have been sent at time *t*, and $P_i(k,t)$ is the length of *kth* packet size over the normalized weight of queue *i*. The WFQ intra-scheduler finally serves a HOL packet or a queue which has the smallest finish number.

2) *Proportional Fair (PF)*

Proportional Fair [12] is a leading channel aware scheduler that balances between throughput and fairness among users. Its scheduling metric is according to the ratio weight, $W_i(t)$, of the current user data rate over its previous goodput whose packet in queue *i* as computed below:

$$W_i(t) = \arg\max \frac{R_i(t)}{D_i(t)} \tag{3}$$

where $R_i(t)$ is the current data rate in bps and $D_i(t)$ is the last average goodput in bps which obtained from the following formula (4) or (5):

If the queue *i* was just served;

$$D_i(t) = (1-\frac{1}{t_c})*D_i(t-1)+\frac{1}{t_c}*R_i(t) \tag{4}$$

or, otherwise;

$$D_i(t) = (1-\frac{1}{t_c})*D_i(t-1) \tag{5}$$

Note that we assume $R_i(0)=D_i(0)$, thus, $W_i(0) = 1$ for the first time sender who initially achieves non-goodput yet. The parameter t_c is called the observation window which is a unit-less time constant tuning between throughput and fairness. The value of t_c has a significant influence in the $R_i(t)$ and directly affects the weight ratio[10]. A smaller number of t_c trades off the throughput with the users fairness where the poor channel users are more likely to be served. On the contrary, the higher value of t_c serving less bad channel users results in higher throughput in the network rather than being fair among users. The PF selects the highest weight to be served.

3) *Greedy or Max-SNR*

A greedy scheduler exploits the channel condition of a SS as a scheduling metric or decision. We consider a report response (REP-RSP) message reporting the average channel quality of CINR (Carrier-to-Interference-plus-Noise-Ratio) every 3s. Then, the scheduler serves the HOL packet in queue *i* instantaneously whose user has the highest CINR.

$$W_i(t) = \arg\max (\mathrm{CINR}_{\mathrm{mean}}(t)) \tag{6}$$

IV. SIMULATION MODEL

A. *Link Level Simulation*

Link level of BER performance simulations for SISO, SM and STBC are initially performed across all modes as published in [7]. The channel model used is the Spatial Channel Model (SCM) by 3GPP and an urban micro 3GPP tapped delay line (TDL) is generated in the link level analysis[10]. Perfect channel estimation and synchronization is assumed. A correlation factor of 0.4 is assumed for the MIMO channels. Our WiMAX simulator implements the STBC Alamouti scheme to provide transmit and receive diversity. In the SM-MIMO, a minimum mean square error (MMSE) receiver is chosen due to its ability to remove the inter-stream interference while reducing the Gaussian noise that is presented in the channel. Figure 2 shows the BER performance of SM MIMO across all modulation schemes. All BER curves produced from the PHY simulator are then exploited to calculate exit and entry thresholds for the link adaptation algorithm in Qualnet. Both thresholds are set at a BER between 10^{-4} and 10^{-5}. The BS uses these thresholds when adopting a suitable transmission mode based on the instantaneous SNR.

B. *System Level Simulation*

The generated BER performance results are incorporated in Qualnet as SNR-BER look-up tables to compute burst errors for the corresponding channel condition. New exit and entry thresholds referring to the generated BER curves are defined in both uplink and downlink for every modulation and coding scheme (MCS) for both a single antenna and multiple antenna techniques. The use of BER tables and threshold values for different MIMO 2x2 algorithms make the Qualnet link adaptation decisions more realistic in regard to the MIMO cases and burst error computation.

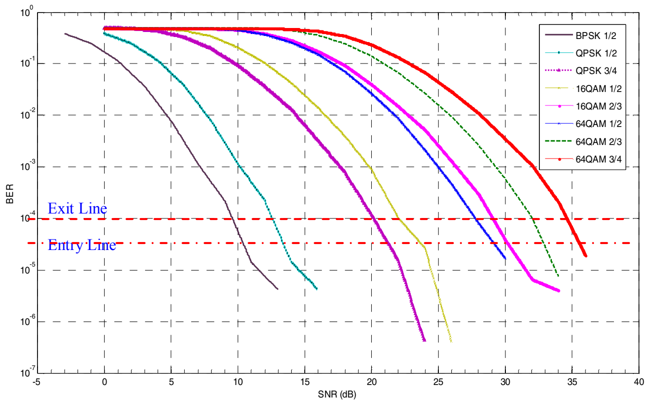


Figure 2. BER vs SNR for SM MIMO 2 x 2 (correlation factor = 0.4)

C. Scenarios

In our downlink scenario, a BS initially communicates to a stationary SS with fixed-size data packets of 1024 bytes at a Constant Bit Rate (CBR). The main system parameters of the simulation model are summarised in Table II. Our first objective is to observe the goodput performance including packet loss and average delay across MCS for the MIMO techniques and also to determine their maximum achievable goodputs relative to the theoretical data rates.

TABLE II. MAIN SYSTEM PARAMETERS OF THE NETWORK SIMULATOR

Layer	**Parameters**	**Value**
PHY	Operating Frequency	2.5 GHz
	PHY Mode	OFDMA
	Duplexing Mode	TDD
	Channel Bandwidth	10 MHz
	FFT Size No of Used Subcarriers Sampling Factor Guard Interval	1024 720 8/7 1/8
	Channel Model Propagation model Propagation Limit Shadowing Model Shadowing Mean	SCME Two Ray Ground -111.0 dBm Constant 4.0
	Antenna Model	Omni directional
	Antenna height	1.5 m
MAC	Number of symbols/frame	198
	DL: UL symbol ratio	99:99
	Link Adaptation and Fragmentation	Enabled
	ARQ	Disabled
	Transport	UDP
	Internet Protocol	IPv4
	Simulation Duration	100 s

The link load varies around the saturation load value; the load is changed using the packet generation interval whilst the packet size of 1024 bytes is constant. The traffic load is calculated as in (7):

$$\text{Traffic Load (bps)} = \frac{\text{Packet Size (bytes) x 8 bits}}{\text{Packet Interval (s)}} \qquad (7)$$

We then consider 3, 6, 10 and 50 users in a cell at the range supporting 64QAM ¾ STBC for WFQ and PF as well as Greedy independently. We configure a CBR traffic load with the packet size of 1024 bytes whilst the PF has two different t_c parameters equals to 500 [13] and 50K [9]. Our aim is to compare the maximum achievable UGS goodput as well as average delay for channel-aware and queue-aware schedulers for a group of users.

V. SIMULATION RESULTS

A. Goodput Performance

Figures 3-5 shows that the achievable user goodput of UGS increases gradually when increasing the traffic load. This is because the network manages thus far to serve the configured traffic load. It can be seen that the user goodput has a linear relationship with the traffic load at the initial stage which is also observed in [8] . The goodput, however, stops increasing at a certain traffic load. This is where the link reaches its maximum goodput as shown by the arrows (see Figures 3-5) with respect to the carried traffic. At this particular point, the maximum goodput is associated with low packet loss as well as low average delay, as shown in Table III for the 64QAM ½ SISO case as an example. The goodput starts falling slightly and then remains flat when traffic load is increased further (see Figures 3-5), which agrees with the observations in [8]. Under this conditions the network is overloaded, which is indicated by significantly higher packet loss and worse average packet delay, whilst the system maintains constant goodput as shown in Table III.

Both SISO and STBC reached similar maximum user goodput for similar traffic loads (see Table IV) but, as expected, at different SNRs. STBC certainly does not improve the maximum goodput, however, it improves the link reliability due to the enhanced BER performance. On the contrary, for SM 2x2, the achievable maximum throughput is double for all modes using MMSE receivers at the link level simulation. Comparing to the theoretical data rates after eliminating the overheads (see Table I), the achievable maximum goodput in Table IV is found to be in the range of 94.5% to 97.0% of the theoretical data rates due to packet losses during the transmission. The BS does not adopt all MCSs for its link adaptation due to the fact that some modes never provide the highest throughput in these channel conditions. The table also shows that SM performs exceptionally well at higher SNRs, as expected, whilst the robustness of STBC in poor channel conditions is its primary advantage over SM.

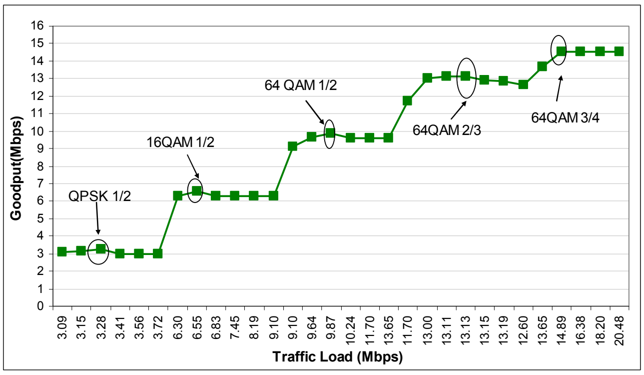


Figure 3. UGS goodput vs. traffic load for SISO

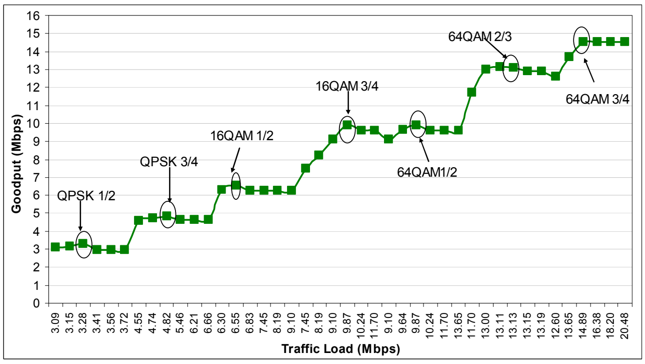


Figure 4. UGS goodput vs. traffic load for STBC

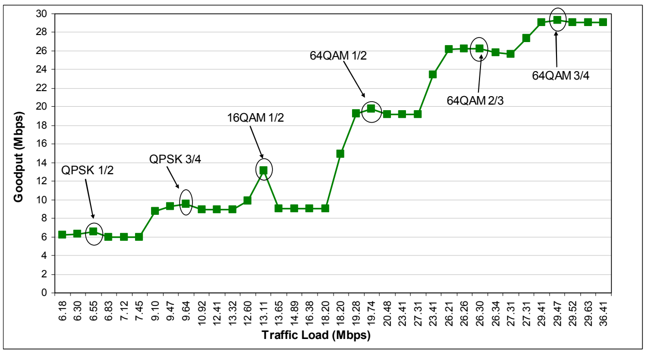


Figure 5. UGS goodput vs traffic load for SM

TABLE III. 64QAM ½ SISO FOR A SINGLE UGS USER SCENARIO

Traffic Load (kbps)	**UGS Goodput (Mbps)**	**Packet Loss (%)**	**Average End-2-End Delay (ms)**
9102.22	9.11	0.01	20.30
9637.65	9.64	0.01	20.60
9869.88	9.88	0.01	21.26
10240.00	9.58	6.59	81.85
11702.86	9.58	18.26	100.67
13653.33	9.58	29.24	103.92

TABLE IV. MAXIMUM GOODPUTS OF UGS USER

Modulation Coding Scheme	**Antenna Technology**	**SNR (dB)**	**Maximum Traffic Load (Mbps)**	**Maximum User Goodput (Mbps)**
QPSK ½	SISO	19.40	3.3092	3.2934
	STBC	6.25	3.2768	3.2701
	SM	20.54	6.5536	6.5504
QPSK ¾	SISO			
	STBC	8.41	4.8188	4.8138
	SM	23.93	9.6376	9.5591
16QAM ½	SISO	23.16	6.5536	6.5504
	STBC	12.49	6.5536	6.5504
	SM	24.93	13.1070	13.1010
16QAM ¾	SISO			
	STBC	14.7	9.8698	9.8671
	SM			
64QAM ½	SISO	30.10	9.8698	9.8601
	STBC	16.07	9.8698	9.8601
	SM	32.15	19.7390	19.7300
64QAM 2/3	SISO	32.16	13.1281	13.1276
	STBC	17.22	13.1072	13.1038
	SM	34.75	26.2986	26.2752
64QAM ¾	SISO	41.23	14.7603	14.7324
	STBC	30.12	14.8945	14.5392
	SM	42.75	29.4676	29.2873

B. *Multiple SSs and Downlink Scheduling Analysis*

As can be seen from Figure 6, the maximum achievable goodput for a group of users in the network supporting 64QAM ¾ STBC is reduced from a single user scenario according to the group size. This is because multiple users generate more overheads, thus, the cell capacity is degraded. However, the type of scheduling for the DL slot explicitly influences the goodput performance as shown in the figure. The enhancements of channel-aware downlink schedulers are more evident for large number of users in the network. The PF with a window size, t_c = 50K achieves higher goodput than t_c = 500 since the high t_c results in a greedy like performance. The bigger value of t_c serves users with good channel longer and delays the users with poor channel and leaves them underserved [9]. The PF with t_c=500 has a lower goodput due to the fact that it considers fairness and behaves similarly as WFQ for this specific scenario. The queue-aware scheduler, WFQ, has considerably the lowest goodput performance compared to the channel-aware scheduler for 50 users in a cell.

Figure 7 shows that for 3, 6 and 10 users facilitate less than 1s average delay across all types of schedulers. However, for 50 users, it is observed that WFQ and PF, t_c = 500, experience longer delay of 2s at the cost of facilitating fairness among users. On the contrary, the PF with t_c=50K achieves lower delay of approximately 1s, whilst the Greedy scheduler achieves the lowest delay as agrees in [14] for a greedy type of scheduler serving VOIP. The trade-off of a greedy scheduler is that it sacrifices the fairness among users though it has the lowest delay from all the simulated schedulers in our scenario.

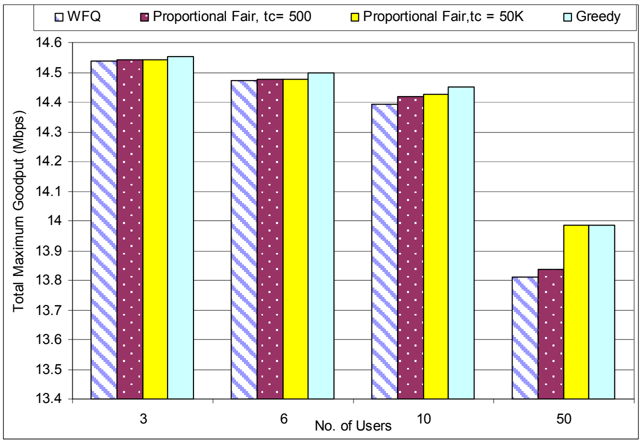


Figure 6. Maximum achievable total goodput by number of users in a single cell for downlink schedulers

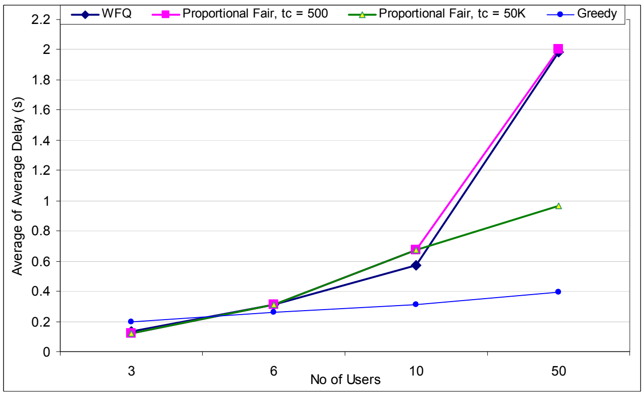


Figure 7. Average of average delay (in sec) by number of users for downlink schedulers

VI. CONCLUSIONS

In this paper, goodput results and its maximum achievable value were initially presented for a single antenna and also STBC and SM MIMO 2x2. New exit and entry thresholds were configured in the Qualnet simulator based on the SNR-BER performances which obtained from a fully compliant 802.16e-2006 link level simulator. The MIMO channel was modeled using the 3GPP spatial channel model. The achievable maximum goodput for a single SS with CBR traffic is found to be between 94.5% and 97.0% of the theoretical data rates. However, a higher number of users significantly reduces the maximum goodput due to the overhead generated and the degree of reduction depends upon the scheduling algorithms employed. When there are 50 users in the cell, the PF with a higher t_c = 50K outperforms the PF with a smaller t_c = 500 and also WFQ since the bigger value of observation window, t_c, results in a greedy like behaviour. The PF with a smaller t_c=500 achieves slightly similar performance as WFQ for a specific scenario. However, the channel aware scheduler generally achieves better capacity as well as better QoS performance against the queue-scheduler. Future work will investigate the interplay between these schedulers for several QoS classes with a distribution of fixed and mobile users.

ACKNOWLEDGMENT

The first author would like to thank Qualnet Support for their supportive forums and also to Zamri Napiah his comments. The first author is also grateful to the Ministry of Higher Education (MoHE) of Malaysia and Universiti Teknologi Malaysia for her funding.

REFERENCES

[1] IEEE Standard for Local and Metropolitan Area Networks Part 16: Air Interface for Fixed Broadband Wireless Access Systems, in IEEE Std 802.16-2004 (Revision of IEEE Std 802.16-2001). 2004. p. 0_1-857.

[2] IEEE Standard for Local and metropolitan area networks Part 16: Air Interface for Fixed and Mobile Broadband Wireless Access Systems Amendment 2: Physical and Medium Access Control Layers for Combined Fixed and Mobile Operation in Licensed Bands and Corrigendum 1, in IEEE Std 802.16e-2005 and IEEE Std 802.16-2004/Cor 1-2005.

[3] Etemad, K., Overview of mobile WiMAX technology and evolution. Communications Magazine, IEEE, 2008. 46(10): p. 31-40.

[4] Alamouti, S.M., A simple transmit diversity technique for wireless communications. Selected Areas in Communications, IEEE Journal on, 1998. 16(8): p. 1451-1458.

[5] Tarokh, V., H. Jafarkhani, and A.R. Calderbank, Space-time block codes from orthogonal designs. Information Theory, IEEE Transactions on, 1999. 45(5): p. 1456-1467.

[6] Ball, C.F., et al., WiMax Capacity Enhancements introducing MIMO 2x2 Diversity and Spatial Multiplexing. Mobile and Wireless Communications Summit, 2007. 16th IST, 2007: p. 1-5.

[7] Tran, M., A. Doufexi, and A. Nix, Mobile WiMAX MIMO performance analysis: Downlink and uplink, Personal, Indoor and Mobile Radio Communications, 2008. PIMRC 2008..

[8] Hoymann, C., Analysis and performance evaluation of the OFDM-based metropolitan area network IEEE 802.16, Computer Networks, Selected Papers from the European Wireless 2004 Conference, 2005. 49(3): p. 341-363.

[9] Valencia, C., Scheduling Alternatives for Mobile WiMAX End-to-End Simulations and Analysis, System and Computer Engineering. 2009, Carleton University: Ottawa, Canada. p. 127.

[10] 3GPP TR 25.996 v6.1.0, "Spatial channel model for Multiple Input Multiple Output (MIMO) simulations," Sep. 2003.

[11] Nuaymi, L., N. Bouida, N. Lahbil and P. Godlewski, Headers Overhead Estimation, Header Suppression and Header Compression in WiMAX, Wireless and Mobile Computing, Networking and Communications, 2007. WiMOB 2007.

[12] Jalali, A., R. Padovani, and R. Pankaj, Data throughput of CDMA-HDR a high efficiency-high data rate personal communication wireless system, Vehicular Technology Conference Proceedings, 2000.

[13] Beh, K.C., S. Armour, and A. Doufexi, Joint Time-Frequency Domain Proportional Fair Scheduler with HARQ for 3GPP LTE Systems, Vehicular Technology Conference, 2008.

[14] M.Nicolaou, A.Doufexi, S.Armour, Y.Sun, Scheduling Techniques for Improving Call Capacity for VoIP Traffic in MIMO-OFDMA Networks, IEEE Vehicular Technology Conference, VTC-Fall, 2009.