Internet Traffic Performance in IEEE 802.16 Networks

Dmitry Sivchenko[1,2,3], Nico Bayer[1,2,3], Bangnan Xu[1], Veselin Rakocevic[2], Joachim Habermann[3]

[1]**T-Systems, SSC ENPS, Deutsche-Telekom-Allee 7, 64295 Darmstadt, Germany**
[2]**School of Engineering and Mathematical Sciences, City University London, London EC1V 0HB, UK**
[3]**University of Applied Sciences Giessen-Friedberg, Wilhelm-Leuschner-Str. 13, 61169 Friedberg, Germany**
Email: {d.sivchenko, v.rakocevic}@city.ac.uk

***Abstract*: The existing wireless technologies are struggling to satisfy the enormous growth of demand on broadband wireless access anywhere and anytime. The IEEE 802.16 standard family has been developed recently, introducing a new air interface for fixed and mobile Broadband Wireless Access. This paper evaluates the performance of the most commonly used Internet applications, such as web browsing, ftp downloading, real-time streaming and email exchange in an IEEE 802.16 based point to multipoint system. The influence of user number, quality of wireless channels and intensity of the subscriber's requirements is intensively evaluated using network simulator ns2. Challenges of Quality of Service establishment in IEEE 802.16 based networks are also investigated in the paper.**

1. Introduction

Currently, the most popular technologies used for wireless access to IP networks are Wi-Fi products based on the IEEE 802.11 standard family, UMTS/GPRS for data transmission in cellular mobile radio networks and Bluetooth (IEEE 802.15.1) usually used for communication among computer devices in the short range. IEEE 802.11 standards with maximal possible 54 Mbps data rates are used for broadband access in Wireless Local Area Networks (WLAN), often called wireless hotspots. UMTS offers wireless access with currently maximal data rate of 384 Kbps in mobile radio networks with generally large coverage. However, there is a rapidly growing demand for new technologies providing Broadband Wireless Access (BWA) on large coverage areas like a cellular network covers with high data rates similar to those of IEEE 802.11.

To satisfy these requirements IEEE working group 802.16 has standardised and is currently further developing a new air interface to provide subscribers access to wireless networks with peak data rates in the excess of tens Mbps on the large coverage area. The promising performance of future IEEE 802.16 based networks is impressive, providing wireless broadband connections with data rates of up to 70 Mbps for subscribers placed up to 50 km away from the base station. The coverage quality of base stations is significantly enhanced due to support of non-line of sight capability. Furthermore, although the specified air interface initially focused on fixed wireless access only, further developments will also enable broadband wireless networking for mobile users. The potential of IEEE 802.16 systems has prompted the worldwide advancement of the new standard. The standardisation process obtained a strong support from an union of industry leaders who organised Worldwide Interoperability for Microwave Access (WiMAX) consortium, focused on the open compliance of all products used for BWA. All products that passed the interoperability tests for the IEEE 802.16 standard receive a WiMAX certification mark.

However, although the theoretical possible capabilities of WiMAX networks fascinate, they often are calculated too advantageously and can never be achieved under real conditions. What is the realistic service a WiMAX system can really offer to users is an essential question today. Some interesting publications dealing with this theme have recently been presented, e.g. [2] contains initial analysis of IEEE 802.16 based systems. The author concentrates on the primary performance of the system, like coverage ranges of a WiMAX base station, optimal payload length depending on the current error rate or maximal throughput in a cell. These results reveal the common aspects of maximal possible communication quality available for a couple of users, however, they cannot show actual problems to be expected in future WiMAX based networks since the properties and behaviour of users in real IP wireless networks are not considered.

Hence, the main objective of our work is to fill this gap by assessing the performance in WiMAX based networks when the behaviour of real users is followed. This refers to the different wireless channel characteristics of all subscribers distributed on the coverage area of the base station and various data sessions every user manages. The paper investigates the expected performance in a real WiMAX cell and denotes main factors influencing it.

The paper is organised as follows: Section 2. contains a short introduction on the IEEE 802.16 standard in order to facilitate the understanding of the following discussions, Section 3. describes the implemented model of a WiMAX system. Performance evaluation is presented in Section 4.. Section 5. concludes the paper and gives an insight into our future work.

2. IEEE 802.16

In this section we introduce the features of the IEEE 802.16 standard which are the most important for the performance providing in WiMAX networks. The IEEE 802.16 standard basically supports a point-to-multipoint (PMP) operation mode, where a typical cell consists of a Base Station (BS) with a number of Subscriber Stations (SS). Optional Mesh network architecture is defined in the standard, whereby in the PMP mode data transmissions are only possible between the BS and SSs, while in the Mesh mode SSs may also communicate with each other. Four different physical transmission modes are defined in the standard with support of

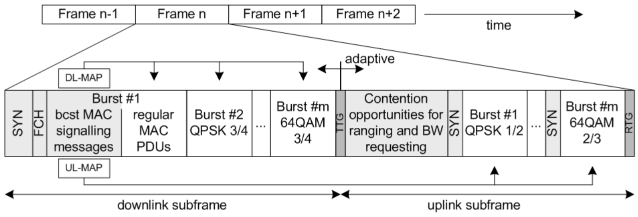

Figure 1: Frame structure of IEEE 802.16 PMP

frequency and time division duplexing (FDD and TDD). We consider in our work orthogonal frequency division multiplexing (OFDM) PHY layer using TDD and PMP network architecture.

Data units between the BS and SSs are transmitted by means of fixed-length frames. The structure of a frame is shown in Figure 1. It consists of a down- and an uplink subframe, whereas the downlink subframe is used to transfer user data from the BS to SSs and the uplink for data transfer in reverse direction. At the beginning of the downlink subframe a preamble for synchronisation is transmitted, followed by the broadcast MAC signalling messages. Thereafter the bursts consisting of user data are transferred to particular SSs using different modulation types and coding rates. The Tx/Rx transition gaps are inserted between the subframes to allow stations to switch between transmission and reception operation modes. The uplink subframe begins with contention intervals scheduled for initial ranging and bandwidth request opportunities. Initial ranging is used e.g. during network entry by new SSs to adjust their time and power parameters. Within a bandwidth request interval a SS may indicate its need of resources to transmit data to the BS.

The border between two subframes is adaptive according to the data amount in downlink and uplink. Every frame consists of an integer number of OFDM symbols carrying MAC datagrams. These OFDM symbols comprise MAC resources available for data transmissions. Sharing of MAC resources between SSs is centralised in the BS. Downlink and uplink map (DL-MAP, UL-MAP) signalling messages are used to inform SSs about bandwidth allocations in downlink and uplink.

A maximal possible bitrate on the MAC layer in an error-free wireless channel can intuitively be calculated according to Equation 1.

$$T = N_{\frac{frames}{sec}} \cdot N_{\frac{symbols}{frame}} \cdot N_{\frac{bits}{symbol}} \qquad (1)$$

where $N_{\frac{frames}{sec}}$ depends on the frame length, $N_{\frac{symbols}{frame}}$ on the frame length and symbol duration and $N_{\frac{bits}{symbol}}$ on the used modulation type and coding scheme. However, bitrates available for transmission of user data are less as synchronisation preambles, contention intervals, MAC signalling messages, which should be transmitted with most robust modulation dramatically decrease the number of remaining free OFDM symbols. Table 1 contains raw bitrates for all possible modulation types and coding rates ([1]). It can be seen that more robust modulation techniques are less effective. For example, to transmit a

Modulation technique	Useful bits in OFDM symbol	Raw bitrate, [Mbps]	Ratio
BPSK 1/2	96	2.82	9
QPSK 1/2	192	5.65	4.5
QPSK 3/4	288	8.48	3
16-QAM 1/2	384	11.29	2.25
16-QAM 3/4	576	16.94	1.5
64-QAM 2/3	768	22.59	1.125
64-QAM 3/4	864	25.41	1

Table 1: Characteristics of modulation techniques

MAC frame of 1500 bytes, 14 OFDM symbols are required with 64-QAM 3/4 modulation technique, while 125 symbols are needed to do the same with BPSK 1/2. Therefore, a fragmentation mechanism is very important especially for users with less effective modulation techniques. Using this mechanism a data packet can be transmitted in several frames so that an SS can use allocated MAC resources even if they are insufficient to transmit the whole data unit in a frame at once.

The implementation of the scheduling mechanism to share available MAC resources between requesting SSs represents a big challenge. The ratio in the last column of the Table 1 shows coefficients of decreasing efficiency of modulation techniques. Thus, disposing the same number of OFDM symbols, a nine times higher throughput can be provided to an SS with 64-QAM 3/4 than to another one with BPSK 1/2. In our work we have developed a scheduling algorithm where identically prioritised SSs get enough MAC resources in order to obtain equal throughput. If a BS has free OFDM symbols insufficient to satisfy requirements of all SSs, the maximal possible throughput that can be provided to every SS with available MAC resources is determined. Thereby modulation type and coding rate of every requiring SS is considered. Then a number of OFDM symbols needed to provide the determined throughput is allocated to every SS according to its modulation technique.

3. Simulation model of a WiMAX system

To assess the performance of Internet traffic in WiMAX based wireless networks we have implemented the basic PMP mode of the IEEE 802.16 standard in the network simulator ns2 [8]. The whole MAC and PHY layers functionality such as network entry process, IP connection establishment, bandwidth request and allocation algorithms, frame based data transmission and adaptive modulation mechanism are adopted in our implementation. Figure 2 shows the reference scenario of simulations that is a typical WiMAX cell consisting of a base station and a number of subscriber stations. The circles around the BS show its coverage ranges with corresponding modulation type and coding rate. An SS can move within the coverage area of the BS, thereby the adaptive modulation mechanism works and the data frames between the BS and SSs are transmitted applying different modulation techniques according to the varying characteristics of SS's wireless channel. SSs are ran-

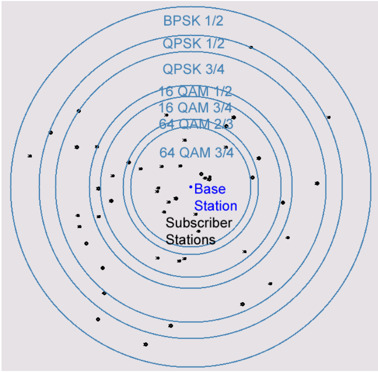

Figure 2: Reference scenario with 30 subscriber stations

domly placed around the BS, thereby the maximal distance between them is limited due to the minimal desired modulation technique, i.e. all SSs have modulation type and coding rate of this or higher efficiency. SSs are equally prioritised with the best effort quality of service. However, a parameter of Maximal Information Rate (MIR) is introduced that defines the maximal throughput, a subscriber station may be allocated to. E.g., if a user requires a throughput of 1300 Kbps, while MIR is 1000 Kbps, the user is allocated the maximal MIR if the BS has sufficient MAC resources. In the case the BS is overloaded and has insufficient resources to satisfy requirements of all users, they obtain equal possible throughput as it has been explained in Section 2..

Typical Internet traffic types like ftp downloads, cbr real-time streams, web browsing using http and email service ([3], [4] and [5]) are managed by the SSs, their exact parameters can be found in [6]. The BS acts as a web, ftp and cbr servers, it is also a destination server for emails sent by the SSs.

In our simulations we use a channel bandwidth of 7 MHz, the frame length is 10 ms and the cyclic prefix for OFDM symbols is 1/16. All presented results are simulated for the case of rush hour traffic when SSs generate the most traffic.

4. Traffic Performance in IEEE 802.16 networks

Our first investigations aim to evaluate the implication of modulation technique on the BS load for the case there are 20 SSs with MIR of 3 Mbps in the cell. Figure 3a shows the percent usage of available MAC resources according to the minimal modulation of SSs. It can be seen, that with increasing robustness of the minimal modulation the BS load goes up, respectively. Thus, with BPSK 1/2 the BS load is more than 90% during the half of the time since much more resources are needed to satisfy the requirements of all SSs. The time, the BS load is more than 90% depending on number of SSs with MIR of 1 Mbps is shown on Figure 3b. The MAC resources are never used to full capacity by 10 users, while the BS maintaining 50 SSs is overloaded during almost 90% of time.

Figure 4 shows the cumulative distribution function (CDF) of provided throughput for 20 SSs depending

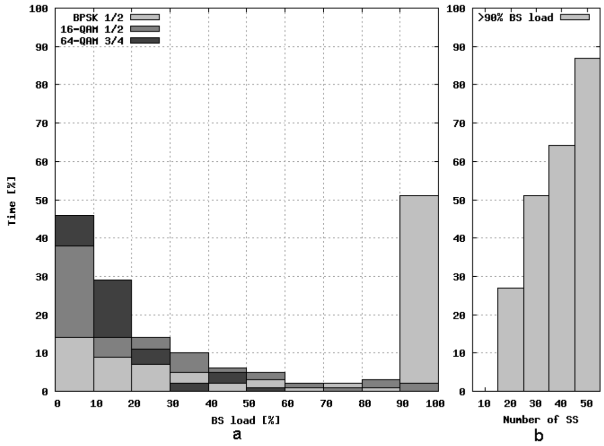

Figure 3: a. MAC usage depending on minimal modulation technique

. b. MAC usage depending on number of SSs

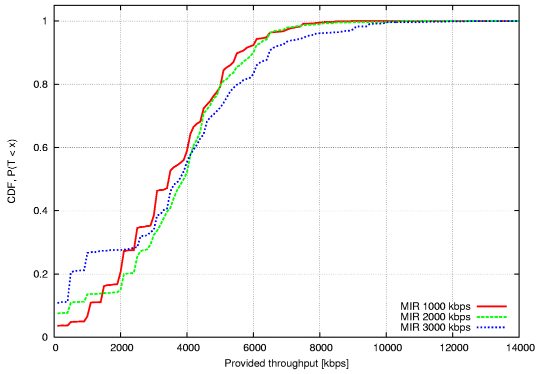

Figure 4: Provided throughput depending on allowed MIR, 20 SSs

on allowed MIR. Using these functions we can predict probability of providing the given throughput in the cell. Moreover, a probability density function can easily be derived from CDF in order to predict exact probabilities of providing a certain throughput. However, observing these results only it cannot be concluded either the provided throughput is sufficient to satisfy all user's requirements or if it is caused by available MAC resources and some users get insufficient resources for their needs. We can suppose that the provided throughput is limited by available MAC resources for throughput above approx. 2 Mbps since the CDFs are nearly identical for different MIR values. Figure 5 clarifies this problem by presenting CDFs for unsupported throughput. Unsupported throughout is the difference between required and provided throughput. For MIR of 3 Mbps only in 50% of time the provided throughput is sufficient to satisfy all users while SSs do not get sufficient resources in 20% of time for MIR of 1 Mbps. Moreover, some other interesting results can be obtained from these results. Comparing results in Figure 4 with those in Figure 3b we can determine the percentage of time when the requirements of all SSs are still satisfied although more than 90% of available MAC resources are used. The exact percentage of time when there are insufficient MAC resources for

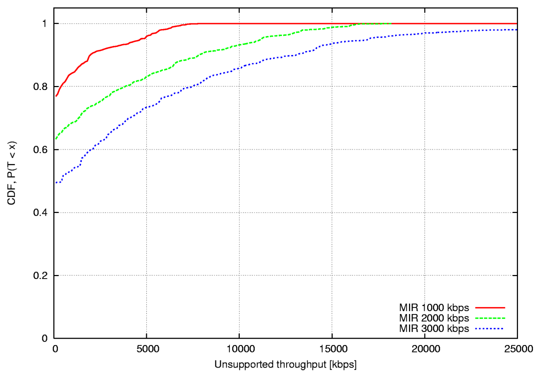

Figure 5: Unsupported throughput depending on allowed MIR, 20 SSs

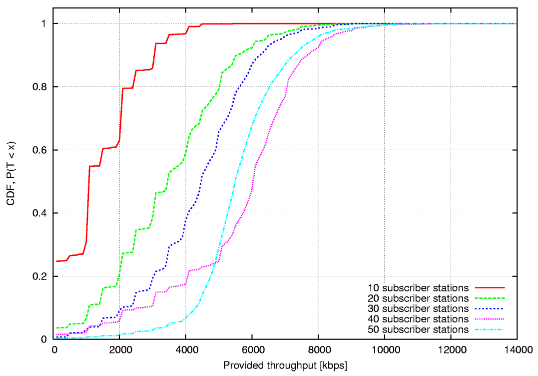

Figure 6: Provided throughput depending on number of SSs, MIR of 1 Mbps

all SSs is 23%, thereby the BS handling 20 subscribers is loaded to 90% in 27% of time. It means, that in 4% of the time the BS is used to full capacity while it can still perform the whole burden of SSs without any losses.

Furthermore, CDFs of unsupported throughput also reveal very good the issue of Quality of Service support in WiMAX systems. It can be seen, that the quality of 1 Mbps cannot be guaranteed even for 20 users handling usual Internet connections, as available MAC resources are sufficient in 80% of time only. To provide it anyway, either the bandwidth of wireless channels have to be expanded in order to increase available MAC resources or characteristics of wireless channels have to be advanced e.g. by increasing transmit power or by using better antennas so that more efficient modulation techniques could be applied and demand on MAC resources reduces.

Figures 6 and 7 show the same CDFs for different number of SSs with MIR of 1 Mbps. Comparing these figures we can also obtain very interesting conclusions about performance degradation for every particular user with increasing number of SSs. Analysing the results presented in Figure 6 it can be seen, that at the certain probability the provided throughput increases with increasing number of SSs. This increase, however, is limited due to available MAC resources. Hence, the more users are served by the BS, the more SSs do not get sufficient MAC resources and, thus, unsupported throughput increases faster. It can also be observed, that the

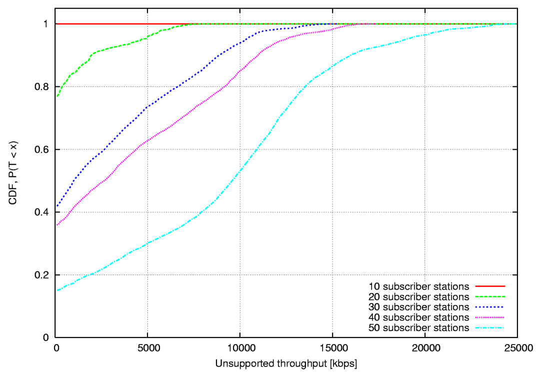

Figure 7: Unsupported throughput depending on number of SSs, MIR of 1 Mbps

provided throughput for 50 users at first increases most rapidly, but then the increase becomes slower so that the provided throughput with 40 SSs is higher. This is because there are more SSs with less efficient modulation techniques in the cell with 50 users, so that disposing the same available MAC resources a higher throughput can be provided for 40 SSs. Hence, the BS serving 50 SSs needs much more MAC resources to satisfy requirements of all users and the common throughput that can be provided by the BS is reduced. The results in Figure 7 also reveal that serving 50 SSs the BS has sufficient MAC resources in 17% of time only.

Further experiments have shown, that the number of SSs with less effective modulation technique is the determinant factor adversely impacting the provided performance.

5. Conclusion

In this paper we have evaluated the performance of Internet traffic in IEEE 802.16 based systems. A typical WiMAX cell consisting of a BS and a number of SSs managing the most commonly used Internet services is considered. The presented results investigate the load of BS, provided and unsupported throughput during the rush hour traffic. Thereby the impact of user number, their modulation techniques and allowed maximal information rate were assessed.

Moreover, problems of Quality of Service establishment in WiMAX networks denoting most significant factors influencing its implementation are indicated.

For our future work we plan to evaluate the Internet traffic performance with varying requirements of SSs that represents behaviour of different user groups. We also plan to get granular on system performance with different profiles of PHY layer, in case a WiMAX network operates at its limit where the BS has to serve even more SSs.

REFERENCES

[1] IEEE 802.16-2004, *IEEE Standard for Local and metropolitan area networks - Part 16: Air Interface for Fixed Broadband Wireless Access Systems*, 2004

[2] C. Hoymann, *Analysis and performance evaluation of the OFDM-based metropolitan area network*

IEEE 802.16, Computer Networks 49, June 2005

[3] N.K. Shankaranarayanan, *Traffic Models for IEEE 802.20 MBWA System Simulations*, Baseline Draft, 16 July 2003

[4] D. Staehle, K. Leibnitz, P. Tran-Gia, *Source Traffic Modeling of Wireless Applications*, Research Report Series, Report No. 261, June 2000

[5] Technology Development Group, Loral CyberStar, Inc., *TCP/IP Performance over Satellite Links - Summary Report*, 29 March 2000.

[6] D. Sivchenko, B. Xu, G. Zimmermann, S. Hischke, *Internet Traffic Performance in High Speed Trains*, in proceedings of HET-NETs 2004

[7] A. Benyamin-Seeyar, *PHY Layer System Proposal for Sub 11 GHz BWA*, contribution of IEEE 802.16 BWA WG, 17 January 2001

[8] *Network Simulator 2*, start page `http://www.isi.edu/nsnam/ns`