Wimax Capacity Estimation through Different Channel Characteristic

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Abstract

In this paper we study the factors influencing system bandwidth capacity in IEEE 802.16e networks. Additionally, we investigate and evaluate the system capacity of 802.16j in order to understand how the relay architecture can lead to capacity increases in the downlink. An analytical study of the WiMAX propagation channel by using Cost-231 Hata Model is presented. This model performed in different frequency bands; the Signal to Noise Ratio (SNR) is achieved under different frequency band as well. The useful bandwidth for WiMAX in the downlink helped us calculate the maximum numbers of subscriber station (SS) based on traffic modeling. Numerical results and discussion highlight the effect of factors over WiMAX capacity; we also simulated the modeling for different system parameters and traffic cases to ease the mobile WiMAX planning using MATLAB.

Keywords: *WiMAX capacity, IEEE802.16j, mobile WiMAX SNR, Cost-231 Hata.*

1. Introduction

Wimax networks are one of the upcoming broadband wireless accesses (BWA) and have a low cost of deployment and support quality of service (QoS). Wimax aims to promote IEEE802.16 by testing and certifying the standard. This is considered to be an alternative to wired networks such as digital subscriber line (DSL) and cable modems links. Wimax networks are able to provide high data rates.

The IEEE802.16 2004 standard was developed to add non-line-of sight (NLOS) application support to the basic standard. The IEEE802.16 standard uses the orthogonal frequency division multiple access (OFDMA) which is one of the most promising multiple access techniques for future wireless networks.

The standard enables the convergence of fixed and nomadic users in the frequency range of 2-11 GHz. In order to add mobility to wireless access, the WiMAX IEEE 802.16e 2005 specification was defined.

Though WiMAX deployment planning has been widely conducted but the explicit planning issue is mostly limited to some practical cases and white papers [2, 4].Thus, in this paper we study the factors that influencing system bandwidth capacity in IEEE 802.16e networks. We also investigated and evaluated the system capacity of 802.16j to understanding how the relay architecture can lead to capacity increases in the downlink. An analytical study of the WiMAX propagation channel by using Cost-231 Hata Model is presented.

The rest of paper is organized as follows: in Section Two we present mobile WiMAX PHY and MAC layers; in Section Three we present the IEEE802.16j mobile wimax relay network; in Section Four we present the simulation results and analysis; in Section Five we introduce the conclusion.

2. PHY and MAC layers in mobile wimax

2.1 OFDM

The WiMAX physical layer is based on an orthogonal frequency division multiplexing OFDM, which is the transmission scheme of choice to enable high-speed data communication in a broadband system. OFDM is based on the idea of dividing a given high-bit rate data stream into several parallel lower bit-rate streams and modeling each stream on a separate subcarrier. This technique helps us minimizing the inter-symbol interference (ISI) [6].In order to completely eliminate the ISI and increase benefit an ISI free channel, a cyclic prefix technique is used. The rate of cyclic prefix to useful symbol time is indicated by G and takes a value of 1/4, 1/8, 1/16, or 1/32.

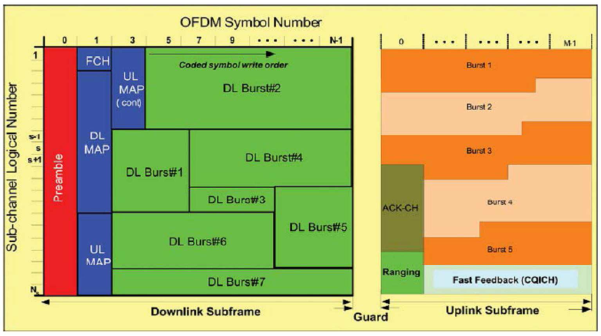

Fig. 1 WiMAX OFDMA TDD Frame Structure [1].

2.2 OFDMA

The total capacity available with a base station is shared among multiple users on a demand basis, using a burst TDM scheme. When using the OFDMA-PHY mode, multiplexing is additionally done in the frequency dimension by allocating different subset of OFDM sub-carrier to different users [7].

There are four different types of sub-carriers in an OFDMA symbol. Data sub-carriers, pilot sub-carriers (used for estimation and synchronization purposes), DC sub-carriers, and Guard sub-carriers (used for guard band).Fig. 1, the general TDD frame structure for WiMAX, (in a 5 ms TDD frame) in DL and UL sub-frame are prorated with a DL:UL ratio and are separated with a 11.4µs transmission Gap.

2.3 OFDMA

In the MAC layer, one or more service data units (SDU) are encapsulated into a protocol data unit (PDU), which is appropriately modulated and mapped onto a PHY frame.
The DL-MAP and a compressed MAP are the broadcasting message; and either of these MAP is the first MAC management message located in the frame. In order to reveal the redundant factors of DL-MAP, we will first examine elements of the MAC PDU since DL MAP is also a MAC PDU [8]. The MAC PDU format of IEEE 802.16 is illustrated in Fig. 2.

The MAC PDU may be mapped onto data sub-carrier of the PHY frame by the following equation:

$$Nd\text{-}sub = BR/MC \quad (1)$$

Where B is the number of bits of in the MAC PDU, M is the number of bits for a subcarrier under a byte of modulation, C and R are the coding rate and the number of repetitions respectively.

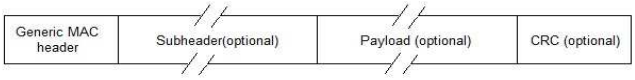

Fig.2 MAC PDU formats [7].

We define the MAC data rate (MDR) as the transmission rate of the data bursts in the frame. This is represented as:

$$MACdata\text{-}rate = NTbits\text{-}OHbits/Tf(bits/s) \quad (2)$$

Where the total number of bits Ntbits represent the total bits that a frame transfers within a frame duration and overhead bits, OH bits are the number of bits used for non-data control message. This include preamble, FCH, DL-MAP, UL-MAP etc. The number of symbols in the TDD/ OFDMA frame in Fig. 1 is calculated from the expression

$$Nsymbol = Tf - (TTG+RTG)/TS \quad (3)$$

Where the symbol time is equal to Tb + Tg, a useful symbol time is $1/\Delta f$ subcarrier spacing and cyclic prefix time Tg is Tb.G The subcarrier spacing can be obtained using the channel bandwidth BW, sampling factor n and FFT size NFFT. According to standard, the sampling frequency FS is (n.BW/8000) x 8000 and the subcarrier spacing Δf is FS/NFFT. therefore, the symbol time is

$$Ts = Tb + Tg = Tb + Tb.G = (1+G)\,Tb = (1+G/\Delta f)$$
$$= (1+G).NFFT/FS \quad (4)$$

And thus

$$Nsymbol = (Tf - (TTG+RTG))/(1+G)NFFT \quad (5)$$

2.4 AMC and Cell-Range Estimation

In order to improve wimax system capacity, coverage, and peak data rate, Adaptive Modulation and Coding (AMC) provides the flexibility to dynamically match the modulation coding scheme (MCS) depending on the signal to noise ratio (SNR) condition of the radio link. When the subscriber is close to the base station (BS), a higher modulation order (64 QAM) with higher code rate is used, and gives the system high capacity. In contrast, the modulation order (16 QAM, QPSK) will decrease when the subscriber is far from the base station (BA) as shown in table I [3].

In this paper the factors that influence system bandwidth capacity in IEEE802.16e networks will be studied. The system capacity of IEEE802.16j is also investigated and evaluated to understanding how the relay architecture can lead to capacity increases in the downlink. An analytical study of WiMAX propagation channel by using Cost-231 Hata Model is presented. Under different frequency band this model performed differently. Likewise, the SNR also achieved differently under unique frequency bands.

The COST-231 Hata model as the path loss model is incorporated. The COST-231 model [6] is an extension to the Hata-Okumura model that has corrections for rural, suburban, and urban areas. The basic path loss equation for suburban areas is:

$$PL[dB] = 46.3 + 33.9\log_{10}(f) - 13.82\log_{10}(h_b) - ah_m + 44.9 - 6.55\log_{10}(h_b)\log_{10}(R) + C_m \quad (6)$$

f is the frequency in MHz, hb is the height of the BS in meters, R is the distance from the BS to the receiver in kilometers, hm is the receiver height in meters, Cm is a standard deviation constant, 0dB for suburban or rural environments and 3dB for urban environments. For suburban or rural areas, the term a (hm) is defined as follows:

$$a(h_m) = [1.1\log_{10}(f) - 0.7]h_m - [1.56\log_{10}(f) - 0.8] \quad (7)$$

And for urban areas, the term a(hm) is defined as follows:

$$a(h_m) = 3.2[\log_{10}(11.75h_m)]^2 - 4.97 \quad (8)$$

$$PL[dB] = PE[dB] - SNR[dB] - N[dB] \quad (9)$$

PE is the emitted power and we consider the case of antennas in BS and user equipment without gain. N is the thermal noise (in units of decibels) which is given by:

$$N[dB] = 10\log_{10}(\tau TW) \quad (10)$$

Where $\tau = 1.38 \bullet 10^{-23}$ W/K-Hz is the Boltzmann constant, T is the temperature in Kelvin (T = 290) and W is the transmission bandwidth in Hz [5].
Using these equations, we can calculate the relationship between the distance and the SNR as follows:

$$R = 10^{\frac{P[dB] - SNR[dB] - N[dB] - 46.3 - 33.9\log(f) - 13.82\log(h_b) + a(h_m) - C_m}{10[44.9 - 6.55\log(h_b)}} \quad (11)$$

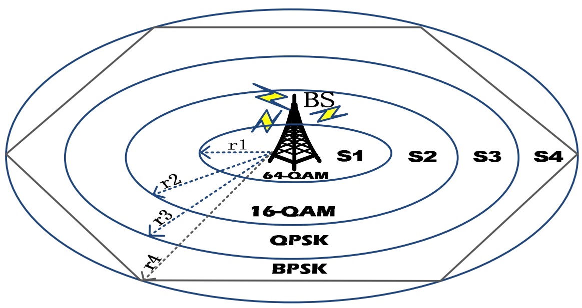

Fig.3 Cell decomposition into regions [11]

Let us consider the following example based on the licensed band for mobile WiMAX at different frequency band and the system bandwidth of 5MHz. At this bandwidth, the thermal noise is equal to (-136.99dB). The transmitted power is fixed and equal to 1W.

The height of the BS antenna is considered to be 35 m above the ground. The SS antenna heights are fixed at 1.5 m above the ground in a suburban environment and the RS antenna is considered to be 27 m above the ground. Considering the above mentioned assumptions in (11) for each value of SNR, a certain amount of distance from BS will be obtained. Considering minimum SNR for each MCS according to Table I, the maximum radii of each MCS region are obtained (as shown in last 5 column's of the table I). Thus, we can determine the area of each MCS region for each scenario with specific conditions. Table II defines the system parameter for capacity estimation [11].

Table 1: Receiver SNR (Values of the IEEE 802.16E)

Modulation	Code rate	Receive r SNR (dB)	Maximum radius for mentioned example (m)				
			2.3 GHZ	2.5 GHZ	3.3 GHZ	3.5 GHZ	5.8 GHZ
BPSK	1/2	3.0	737	680	518	489	299
QPSK	1/2	6.0	604	557	425	401	245
	3/4	8.5	512	472	360	340	208
16-QPSK	1/2	11	420	557	295	279	170
	3/4	14	333	472	134	221	135
64-QAM	2/3	19.0	255	235	179	169	103
	3/4	21.0	224	206.	157	148	90

Table 2: WiMAX Channel Bandwidth Spreadsheet Model

Item	Value	Units	Comments
Base Station	1	#	No. of BS
FFT size	512 1024	#	FFT configuration
Channel size	5 10	MHz	Channel size
Cyclic prefix	1/4,1/8,1/16,1/32	#	CP
N	28/27	#	Sampling factor
Fs	11.2	MHz	Sampling frequency
Tb	91.43	μs	Useful symbol time
Tg	11.43	μs	Guard time CP
Ts	102.86	μs	Symbol time (Tb +Tg)
Tf	5	ms	Frame duration
DL:UL	3:1	#	DL:UL ratio
Path loss model PL	Cost-231 Hata	#	Cost-231 Hata Model
Thermal noise No	-136.99dB	#	

3. IEEE802.16j Mobile Wimax Relay Network

The extension of the standards (IEEE802.16d and IEEE802.16e), IEEE 802.16j aims to define the multi-hop

relay specification including the MAC and the physical (PHY) layers (Fig. 4) [9].
WiMAX uses adaptive modulation and coding AMC. The optimal modulation is automatically selected depending on the signal quality (Fig. 4). For example, if the relay station (RS) or subscriber station (SS) is far away from the nearest base station (BS) the connection is guaranteed to it, but with low-level modulation, this is the maximum speed is slowed down. It is investigated when a signal is modulated with QPSK (Quadrature Phase-Shift Keying) and QAM (Quadrature amplitude modulation) modulation [10].

According to the newest baseline document [9], two modes, non-transparent mode and transparent mode, are specified to support those application scenarios.

4. Simulation Results and Analysis

As show in Fig. 5, the path loss is increased when the distance from the base station increased. Due to the mobile system design, base station (BS) serves all users in the cell area. The hand-off process will occur when the user is located at the cell edge. The highest frequency band of 5.8GHz has a highest path loss among others frequency bands. Frequency bands 3.5GHz with 3.3GHz and 2.5GHz with 2.3GHz have closed path loss; this is because the two carrier frequency gap is small. In a higher frequency band there is trade-off between reduced cell coverage owing to the highest path loss and high data rates for traffic service.

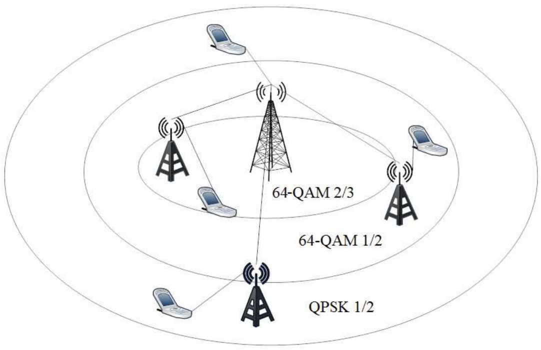

Fig.4 The typical topology of relay network [9, 10]

Fig. 6 shows the relation between the SNR at the receiver and the distance from the transmitter to the receiver. It is worth noting that the optimal RS position is independent of the BS-RS link quality as 64QAM3/4 is maintained on the link independent of the RS position as depicted in Fig. 6.

Fig. 7 shows the SINR of a subscriber station (SS) with different WiMAX frequency bands at different locations from base station (BS). SNR of 2.3GHz is the best among others frequency bands at any distance from base station.

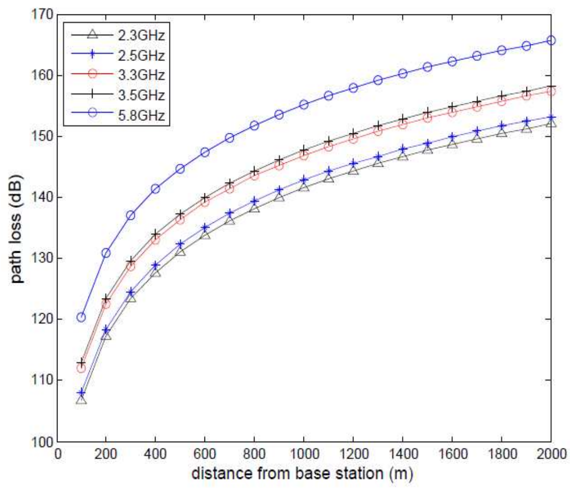

Fig. 5 Path loss vs distance

Also the SNR of 5.8 GHz drops faster than others bands when the distance from the base station increased.

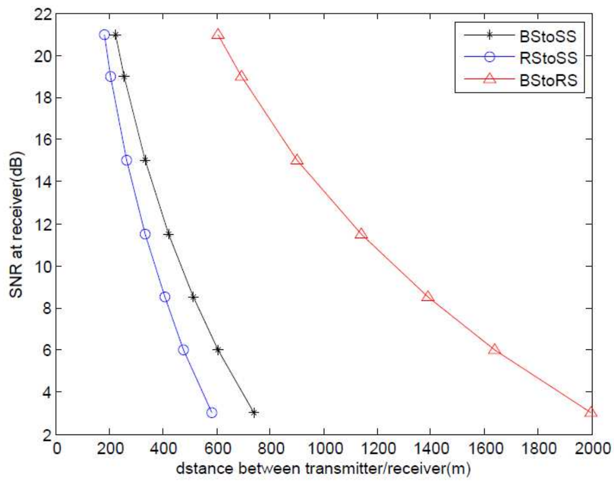

Fig. 6 Distance vs. SNR

Fig. 8 shows the path loss with different wimax frequency bands at different length of the base station (BS). Path loss of the subcarrier utilizing 2.3GHz frequency band is the best among the others frequency bands. The Subcarrier with 5.8GHz experiencing higher level of path loss regardless of how high it is above the base station. We note the path loss is decreased when the higher of base station is increased in all frequency groups.

Fig. 9 shows the cell radius of the base station (BS) coverage with different WiMAX carrier frequency bands at different Modulation and Coding Schemes (MCS). The result shows that the cell coverage when we utilize 2.3GHz is the best among the others frequency bands. Sub-carriers with 5.8GHz experiences smaller coverage at all distance from base station (BS).

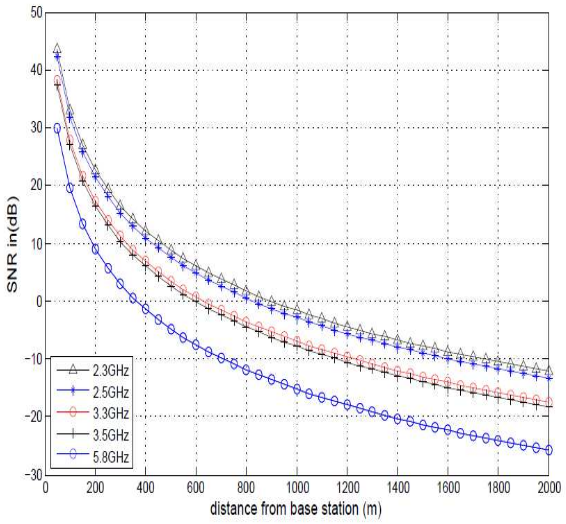

Fig. 7 SNR vs distance

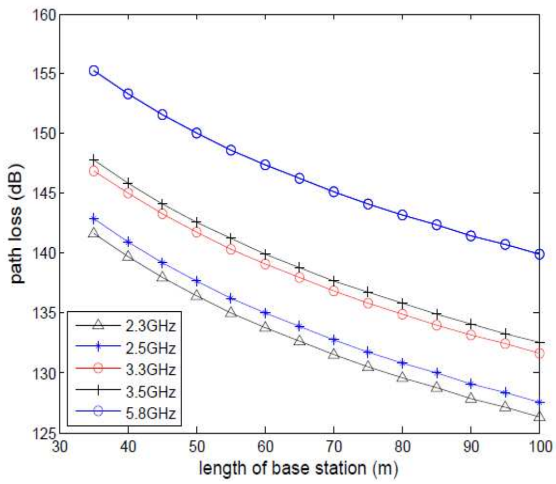

Fig. 8 Path loss vs length of base staton

Fig. 10 shows capacity per subcarrier with the distance from the base station. The capacity decreased as the distance increased; the 2.3GHz frequency band supports highest capacity of all frequency bands.

Fig.11 shows the capacity of mobile wimax with the number of relay station (RS). The result shows that when the number of RS deployed in the coverage of base station (BS) increased, the system capacity increased.

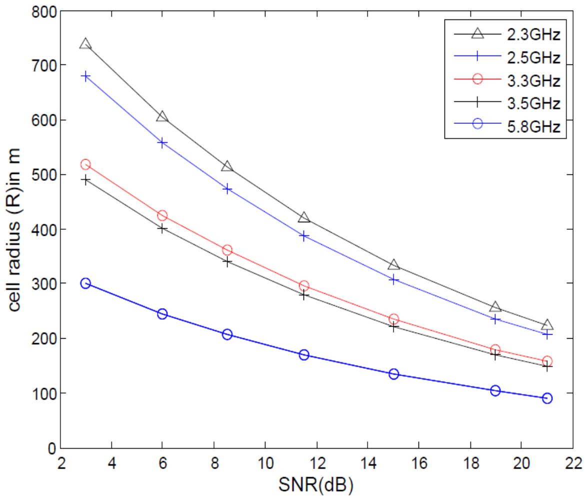

Fig. 9 Cell radius vs SNR

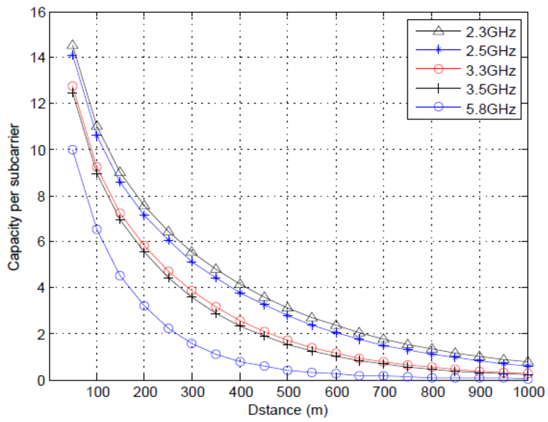

Fig. 10 Capacity per subcarrier vs distance

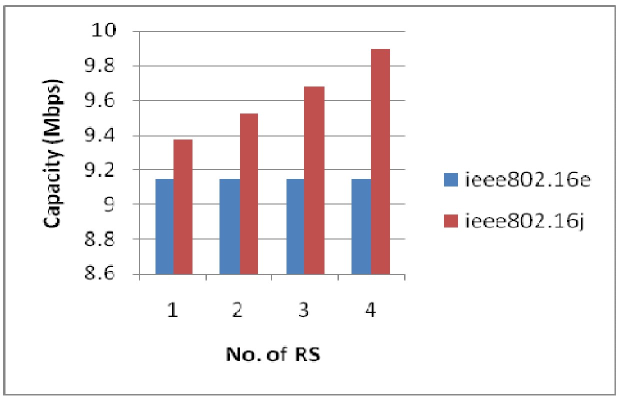

Fig. 11 Capacity vs. number of RS

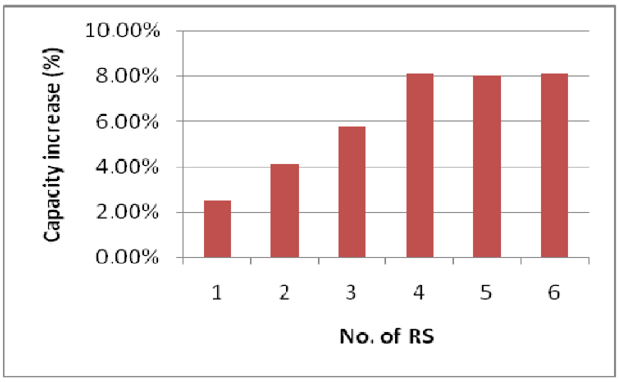

Fig. 12 Capacity increase vs. number of RS

Fig.12 shows that percentage of mobile wimax capacity increased with the number of relay station (RS). The results shows that when the number of RS deployed in the coverage of base station (BS) increased, the overall system capacity is increased on the DL by approximately 8% compared to a traditional 802.16e system. If the number of RS is more than 4, then the result shows that there is no capacity increased. Thus, the BS cell is properly covered by this amount of relay station; additional relays do not have a significant impact on the system capacity.

4. Conclusions

Efficient and optimal utilization of available bandwidth resources has always been a matter of deep concern for engineers designing and implementing Wimax networks. In this paper, we introduced the analytical study over wimax channel characteristic for different frequency bands and different modulation coding schemes. the results shows that the wimax channel with a lower frequency performs better than those with higher frequency bands in aspects of SNR, path loss, cell radius and system capacity estimation .

Instant capacity increased when deploying relay station (RS) in the base station (BS) area coverage. This specific location of RS was chosen as it ensures the highest signal strength possible on the RS-SS link and thus maximizes the reachable capacity increase.

Deploying 4 relay station (RS) to one base station has the most impact over network capacity, this happens because the BS cell is properly covered by this amount of relay station and additional relays do not have a significant impact on the system capacity.

Acknowledgment

This work was supported by the National Science and technology Major Project: Wireless Innovative Campus Area Networks (Grant No. 2010ZX03005-003). The authors greatly acknowledge their supports.

References

[1] Mobile WiMAX - Part I: A Technical Overview and Performance Evaluation. Copyright 2006 WiMAX Forum.

[2] "Air Interface for Fixed and Mobile Broadband Wireless Access Systems", IEEE P802.16e/D12, February, 2005.

[3] WiMAX Capacity White Paper- SR Telecom Canada, August 2006. http://www.srtelecom.comlenlproducts/whitepapers/WiMAX Capacity. pdf.

[4] M. Mousavi, S. Chamberland and A. Quintero, "A New Approach for Designing WiMAX Networks", IEEE CCECE 2007, pp.487-490, 22-26 April 2007.

[5] D. Lois and T. Scelles "WiMAX Network Quality of Service," ATDI White Paper- June2005. http://www.atdi.comldocs/ wP_WiMAX traffic analysis_ eng.pdf

[6] A.M. Ahmadzadeh,Capacity and cell-range estimation: An M.Sc thesis University College of Borås,2008.

[7] J. G. Andrews, A. Ghosh, and R. Muhamed, Fundamentals of WiMAX, Prentice Hall, New York, 2007.

[8] M. Pidutti. 802.16 Tackles Broadband Wireless QoS Issues. Comm.Design,December 2004.

[9] Wang W., Guo Z., Cai J., Shen X. S., Chen S. Multiple frequency reuse schemes in the two–hop IEEE 802.16j wireless relay networks with asymmetrical topology // Computer Communications. – Elsevier, 2009. – No. 32. – P. 1298–1305.

[10] Nuaymi, L. WiMAX – Technology for Broadband Wireless Access. – John Wiley and Sons Publication, 2007. – 286 p.

[11] Saeed AL-Rashdy, Qing Guo, Overhead Estimation over Capacity of Mobile Wimax . World Academy of Science, Engineering and Technology 62 2012.

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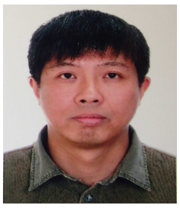

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