COVERAGE PREDICTIONS AND PERFORMANCE ANALYSIS OF SINGLE BASE STATION AND CELLULAR SYSTEMS BASED ON IEEE 802.16 STANDARD

Marko Porjazoski, Borislav Popovski

University "St's Cyril and Methodius",
Faculty of Electrical Engineering and Information Sciences – Skopje
Karpos 2 b.b. 1000 Skopje, R. Macedonia

Abstract

This work provides a approach to evaluate coverage and performance of WiMAX based metropolitan and cellular systems, comprising the most appropriate coverage models currently available (Hata, Walfisch-Ikegami and Stanford University Interim model) and the key system attributes defined in the IEEE 802.16 standard. Coverage and performance estimates are provided, based on real world operation, in accordance to the current European regulatory rules, which respectively handles operation in licensed 3.5 GHz band. For dimensioning single base station WiMAX system, the worst case CNR is relevant parameter. For cellular WiMAX network, interference generated by co-channel cells that utilize the same frequency channel must be considered.

The main contribution of this paper is coverage and performance evaluation of WiMAX systems, assuming ideal transmission power control.

1. Introduction

WiMAX or IEEE 802.16 is a radio access technology that offers performances similar to wired xDSL systems. Different deployment concepts are foreseen for WiMAX networks. They can cover metropolitan or isolated areas, private campus networks, and remote neighbourhoods. Even more WiMAX can be deployed as a cellular network that offers ever-present broadband services over large geographic regions to mobile subscribers.

Detailed procedures for coverage prediction and performance evaluation of IEEE 802.16 networks are not yet clearly stated in the literature for general operation conditions. This situation is result of lack of appropriate coverage prediction models that comply with operation frequencies requirements of WiMAX, especially for frequencies ranging from 2 GHz up to 6 GHz.

Coverage and performance predictions for metropolitan and cellular systems based on 802.16 standard is in the focus of our work. For these purposes, we are using different path loss propagation models (like Hata, Walfisch-Ikegami and SUI). These models are suitable for modelling different LOS and NLOS operation scenarios, despite the fact that they are inherited from techniques for radio network planning for earlier mobile and wireless systems.

The remaining of this document is organised as follows: Section 2 presents key features of the IEEE 802.16 standard and the major aspects of the technology. Section 3 describes the coverage and performance evaluation of WiMAX wireless networks, based on appropriate propagation models, as well as on analytical formulas for the OFDM receiver sensitivity and maximum data transmission rate. In Section 4, some basic concepts on WiMAX cellular system dimensioning and deployment are explained. Section 5 concludes the paper.

2. OFDM and IEEE 802.16 technology

Basic architecture of IEEE 802.16 based wireless networks comprises Base Station (BS) and Subscriber Station (SS), operating in Point – to – Multipoint mode. BS coordinates medium access control and SS provides network access to the subscriber via a wireless link to the BS. IEEE 802.16 systems can operate in different LOS or NOLS environments. The first step to enable NLOS propagation is to reduce the carrier frequency below 11 GHz. Furthermore, by using appropriate techniques, we can take advantage on multipath that appears at the lower frequencies.

The key technique that enables NLOS operation of WiMAX is Orthogonal Frequency Division Multiplexing (OFDM). OFDM operation consists of multiplexing information on N narrowband sub-channels, each modulated by a set of orthogonal sub-carriers.

The OFDM scheme specified in the IEEE 802.16 standard is presented in Figure 1. The OFDM symbol is composed of a useful symbol interval (Tb) and the guard interval (Tg), named Cyclic Prefix (CP). The resulting symbol duration is Ts = Tb + Tg, (Figure 1a).

OFDM spectrum consists of different types of sub-carriers (Figure 1c). Only data sub-carriers are employed for data transmission. Other sub-carrier are used for channel estimation and and inclusion of guard bands between groups of sub-carriers.

In addition to OFDM multiplexing, adaptive modulation is adopted in the IEEE 802.16 standard. Depending on the signal-to-noise ratio (SNR) at the receiver, the SS and the BS negotiate the most appropriate modulation scheme, among the available options (BPSK, QPSK, 16 QAM and 64 QAM). Adopted modulation and coding schemes, defined in the IEEE 802.16 standard, along with the required SNR are listed in Table 1.

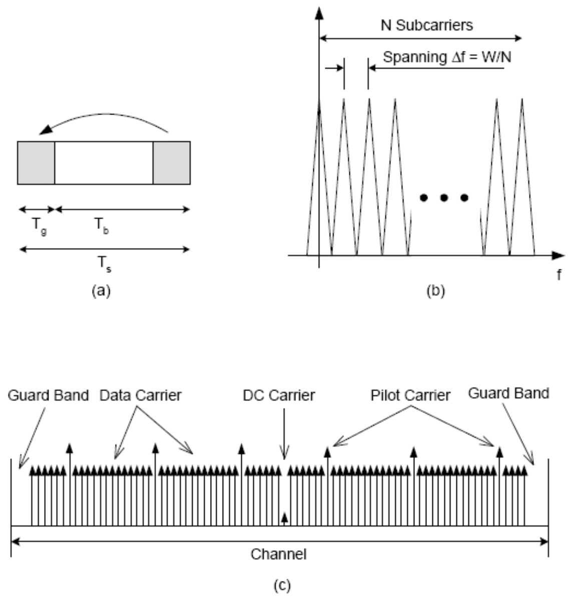

Figure 1. OFDM technique in IEEE 802.16: (a) symbol structure; (b) orthogonal subcarriers; (c) data, DC and pilot subcarriers.

Coding schemes defined in the IEEE 802.16 standard, along with required SNR

Modulation	Coding	SNR
BPSK	1/2	6.4
QPSK	1/2 3/4	9.4 11.2
16-QAM	1/2 3/4	16.4 18.2
64-QAM	2/3 ¾	22.7 24.4

3. Coverage and performance prediction of single BS WiMAX system

Coverage and performances of any wireless system are closely related to propagation loses in wireless environment. Propagation loss estimation is a key factor in wireless network planning.

Link budget calculation (see equation 1) defines maximum propagation loss tolerated by system in the specific scenario.

$$P_r = \frac{P_T \cdot G_{BS} \cdot G_{SS}}{L_T} \quad (1)$$

P_r is received power, P_T is transmission power, G_{BS} and G_{SS} are BS and SS antenna gains, and L_T is total system loss including radio propagation loss *PL*, cable losses and fading margin.

Signal to (Noise + Interference) ration is defined by:

$$SNR = \frac{P_r}{P_N + Int} \quad (2)$$

where $P_N = kTWF$ is thermal noise power at the receiver with effective channel bandwidth *W*, noise figure *F*, at temperature *T* in Kelvin. $k = 1.38 \times 10^{-23}$ J/K is Boltzmann's constant. *Int* is a interference caused by the neighbouring BSs, and in the single BS scenario *Int*=0.

Having in mind required SNR for modulation formats defined by the IEEE 802.16 standard, we can calculate receiver sensitivity $P_{r,min}$ as:

$$P_{r,\min} = SNR_{t\arg et}\left(kTWF + Int\right) \quad (3)$$

Taking into considerations the European regulations about maximum EIRP in the 3.5 GHz band, and using appropriate formula (model) for path loss propagation, we can evaluate coverage for WiMAX system. We are using three different path loss propagation models Hata, Walfisch – Ikegami and SUI, for different deployment arrays: urban, sub-urban and rural.

Having in mind that OFDM scheme in IEEE 802.16 standard does not allocate the entire channel bandwidth for information transmission, the effective bandwidth *W* can be computed as:

$$W = \left\lfloor \frac{n \cdot BW}{8000} \right\rfloor \cdot 8000 \cdot \frac{N_{used}}{N_{FFT}} \quad (4)$$

where *n* is the sampling factor and *BW* is the channel bandwidth in Hz, N_{used} are data carriers and N_{FFT} are all available sub-carriers,

Finally, receiver sensitivity for OFDM can be calculated as:

$$P_{r,\min} = SNR_{t\arg et}\left(kTF \cdot \left\lfloor \frac{n \cdot BW}{8000} \right\rfloor \cdot 8000 \cdot \frac{N_{used}}{N_{FFT}}\right) \quad (5)$$

Parameters, specified by IEEE 802.16d standard, that we are going to use in our calculations are listed in Table 2.

Table 2. OFDM Parameters, According To IEEE 802.16 Standard

Parameter	OFDM value
Nused	192
N_{FFT}	256
G	1/4, 1/8, 1/16 and 1/32
n	8/7, for BW a multiple of 1.75 MHz

In order to compare WiMAX system behaviour in different deployment environments, we used three widely adopted path loss models:

- Hata model-for urban arrays:

$$\begin{aligned} L &= 46.3 + 33.9\log f - 13.82\log h_{te} - a(h_{re}) \\ &+ (44.9 - 6.55\log h_{te})\log d + C_M \end{aligned} \quad (6)$$

where

$$a(h_{re}) = 3.2(\log 11.75 h_{re})^2 - 4.97 \quad dB$$

$$C_M = \begin{cases} 0\,\text{dB} & \text{for medium sized city} \\ 3\,\text{dB} & \text{for metropolitan centers} \end{cases}$$

f is a carrier frequency h_{te} and h_{re} are BS and SS antenna heights respectively.

- Walfisch-Ikegamimodel-for suburban arrays:

$$L = \begin{cases} 42.64 + 20\log(f_C) + 26\log(d) & if\ d < d_C \\ 42.64 + 20\log(f_C) + 26\log(d_C) & if\ d \geq d_C \\ + 40\log(d/d_C) & \end{cases} \quad (6)$$

where $d_C = 4h_t h_r/\lambda$ is the break-point distance, with h_t and h_r being the transmit and receive antenna heights, respectively.

- SUI model for rural arrays:

$$L = A + 10\gamma \log\left(\frac{d}{d_o}\right) + \Delta L_f + \Delta L_h \qquad (7)$$

where:

$$d_o = 100 \text{ m},\ A = 20\log(4\pi d/\lambda)$$
$$\gamma = (a - bh_b + c/h_b)$$
$$\Delta L_f = 6\log\left(\frac{f}{2000}\right)$$

$$\Delta L_h = \begin{cases} -10.8\log\left(\frac{h}{2}\right) & \text{for terrain Types A and B} \\ -20\log\left(\frac{h}{2}\right) & \text{for terrain Type C} \end{cases}$$

Parameters a, b and c specifies different type of terrain, where WiMAX system is planed to be deployed. They are listed in Table 3.

Table 3. SUI model parameters

Parameter	Terrain A Mountains	Terrain B Hills	Terrain A Flat Terrain
a	4.6	4	3.6
b	0.0075	0.0065	0.005
c	12.6	17.1	20

For detailed coverage and performance evaluation we have assumed SS antenna height h_r = 3 meters, BS antenna heights h_t = 30 meters, carrier frequency f_c = 3.5 GHz band this braking distance d_C = 4200 meters.

Table 4. Estimated Uplink/Downlink Coverage Radius In Km

Radius [km]	BW=7 MHz, P_t = 30 dBm, $G_{BS} = G_{SS}$ = 3dBi						
	BPSK	QPSK		16-QAM		64-QAM	
	1/2	1/2	3/4	1/2	3/4	2/3	3/4
W-I	2.49	1.9	1.62	1.02	0.87	0.58	0.50
Hata	1.2	0.98	0.87	0.62	0.55	0.41	0.37
SUI – Type 2	0.86	0.73	0.67	0.5	0.46	0.36	0.33

By using equations (1) - (7), considera-tion the maximum BS and SS transmission of 30 dBm, channel bandwidth 7 MHZ, antenna gains of 3dBi, we can evaluate maximal distance between BS and SS, and maximum achievable data rate trough the radio interface. Results from the evaluation are presented in Table 4 Table 5 and Figure 2, Figure 3.

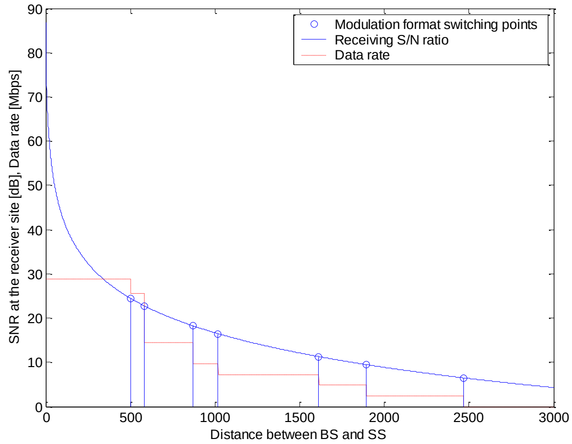

Figure 2. SNR, Bit Rate and Modulation Switching point dependence on BS-SS distance for W-I path loss model

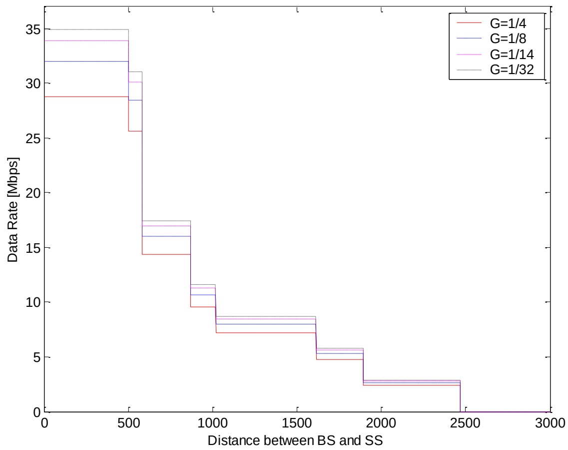

Figure 3. Bit Rate dependence on cyclic prefix duration and BS to SS distance for W-I path loss model.

From the presented result, it is clear that maximum data rate approximately 35 Mbps can be achieved with 64-QAM modulation format and ¾ coding rate. But this modulation scheme provides worst coverage. When increasing the distance between BS and SS, level of SNR at the receiver site is decreasing. At certain point, SNR becomes to low to support ongoing modulation format.

Table 5. Maximum transmission data rates trough IEEE 802.16 Air Interface in Mbps

	BPSK	QPSK		16-QAM		64-QAM	
G	**1/2**	**1/2**	**3/4**	**1/2**	**3/4**	**2/3**	**3/4**
1/4	2.4	4.8	7.2	9.6	14.4	25.6	28.8
1/8	2.66	5.33	8	10.66	16	28.44	32
1/16	2.82	5.64	8.47	11.29	16.94	30.11	33.88
1/32	2.90	5.81	8.72	11.63	17.45	31.03	34.90

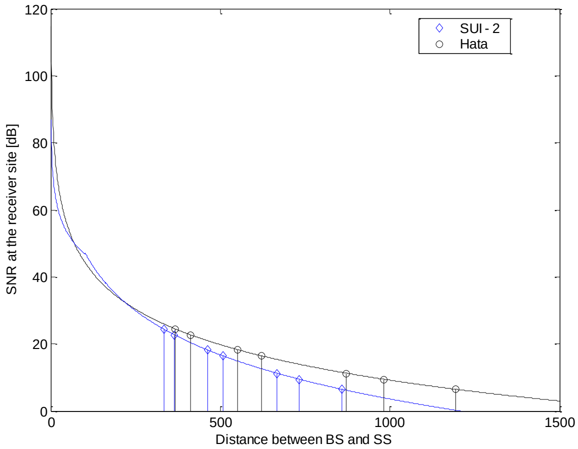

Figure 4. Comparison of SNR and modulation switching points dependence on BS-SS distance for Hata and SUI path loss models

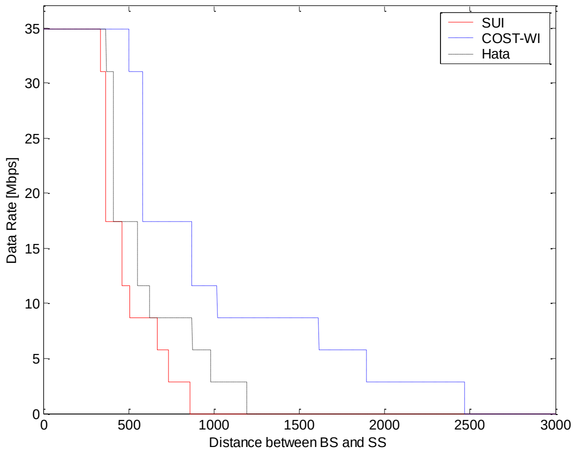

Figure 5. Comparison of achieved bit rate for different path loss models

The system is trying to maintain the connection so it switches on lower modulation format with lower data rates. At some distance SNR becomes so low (< 6.4 dB), that BS can't provide any service to the SS.

Figures 4 and 5 provide comparison of behaviour of WiMAX system in different deployment environments in the mean of coverage areas and supported bit. Severe propagation conditions decreases SNR and supported data rates more quickly with the distance, presenting smaller coverage arrays.

According to this analysis, coverage array of WiMAX system in NLOS scenarios is:

- 2.5 km according to Walfisch – Ikegami model
- 1.2 km for Hata propagation model and
- 0.86 km for SUI model.

4. Dimensioning Cellular WiMAX

In order to cover grate geographical regions, with limiter number of radio channels, wireless systems are organized in cells. To avoid interference in cellular networks, cells are organized into clusters, assigning unique frequentcy for each cell in the cluster (Figure 6).

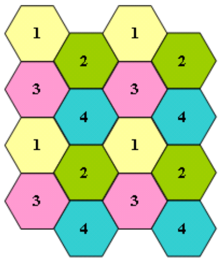

Figure 6. Cellular system with cluster order 4

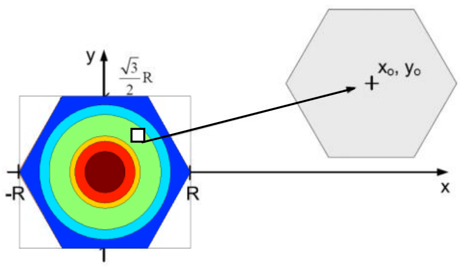

Figure 7. Co-channel interfering cells

BSs and SSs from the co-channel cells introduce interference into system. In order to minimize interference, we have adopted ideal power control, meaning that transmission power at each

SS is set to minimal value satisfying required Signal to (Noise + Interference) Ration (SNIR), at the receiver site at its own BS. Maximum transmission power is limited to 30 dBm.

Two interfering co-channel cells are presented in Figure 7. The cell of interest have BS with coordinates (x_0, y_0), and co-channel cell that generates interference with BS located at (0, 0). Zones in the cell supporting different modulation formats are represented with different colours, starting with BPSK at the cell boundary, up to 64-QPSK at the centre of the cell. Distance between co-channel interfering cells depends on cluster size. Mean uplink interference level at the BS located at (x_0, y_0) can be calculated averaging received signal from users located at co-channel cell.

We will assume that user located at (x, y) transmits with power sufficient to satisfy SNIR at BS located at (0, 0).

$$P_{T,(x,y)} = \frac{SNR_{target} \cdot L(x,y) \cdot (P_N + 6 \cdot Int)}{G_{BS} \cdot G_{SS}} \quad (8)$$

SNR$_{target}$ is required signal to noise ratio, G_{BS} and G_{SS} are BS and SS antennas gain, *L(x,y)* is path loss between SS and its own BS located at (0, 0), P_N is thermal noise power ant *Int* is averaged interference from one of six co-channel cells in the first tire.

Received power or interference that user located at (x, y) causes at observed BS, located at (x_o, y_o), is:

$$P_{R,(x-x_0,y-y_0)} = \frac{P_{T,(x,y)} \cdot G_{BS} \cdot G_{SS}}{L(x-x_o, y-y_o)} = SNR_{target} \cdot (P_N + 6 \cdot Int) \cdot \frac{L(x,y)}{L(x-x_o, y-y_o)} \quad (9)$$

Averaging received signal power from users located in co-channel cell, we can obtain mean interference from one co-channel cell in uplink.

$$Int = \frac{1}{cell\ area} \int_x \int_y P_{R,(x-x_o,y-y_o)} dydx \quad (10)$$

Using equations (8-10) we have evaluated influence of neighbouring cells on maximum coverage in uplink direction that one cell can provide. Results from this evaluation are presented in Figure 8.

Coverage prediction for downlink can be made by using similar method. In downlink case, BSs from neighbouring cells are interference originators.

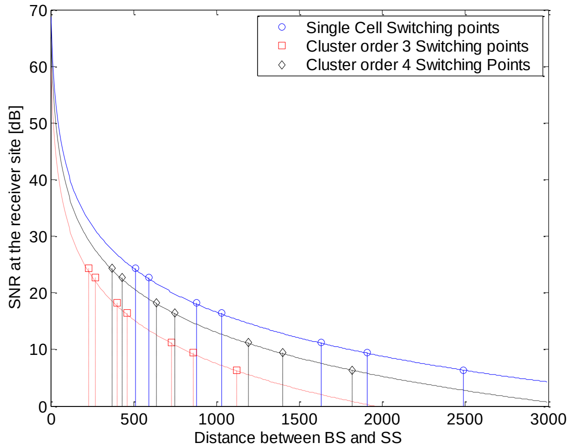

Figure 8. Coverage predictions in uplink direction for WiMAX cellular system with cluster order 3 and 4

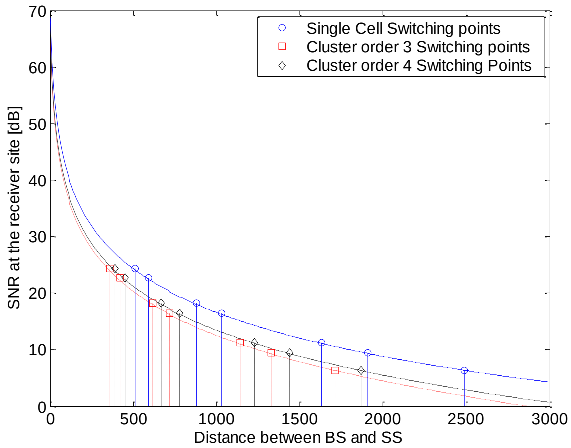

Figure 9. Coverage predictions in downlink direction for WiMAX cellular system with cluster order 3 and 4

We have assumed worst case scenario where BS are transmitting with maximum allowed transmission power.

Results from the downlink analysis are presented in Figure 9.

It is obvious that interference from the neighbouring cells isn't negligible. For systems with smaller cluster sizes interference will cause significant reduction of cell coverage.

5. Conclusion

This work covers evaluation of coverage and performances of WiMAX system. During this evaluation we came to several important conclusions. Performances and coverage of metropolitan or cellular WiMAX systems depends on propagation conditions and path loses introduced by the radio environment.

By using several propagation models and assuming maximum transmission power of 30 dBm we have obtained single BS coverage in NLOS operation mode. For suburban environments maximal coverage of 2.5 km was calculated and maximum data rate of 35 Mbps for users near to BS.

The analysis of cellular WiMAX system shows that interference in both uplink and downlink can cause significant reduction of cell coverage. This problem can be solved by organizing cells into higher order clusters, consuming more non-overlapping channels from limited frequency spectrum.

References

[1]. Theodore S. Rapaport, *Wireless Communications-Principles and Practice*, Prentice Hall, December 2001,

[2]. Hassan Yagohoobi, "Scalable OFDMA Physical Layer in IEEE 802.16 WirelessMAN", Intel Technology Journal, Volume 8, August 2004,

[3]. Christian Hoymann, "Analysis and performance evaluation of the OFDM-based metropolitan area networks IEEE 802.16", Elsevier Computer Networks, No. 49, May 2005,

[4]. Christian Hoyman, Stephan Goebbels, "Dimensioning Cellular WiMAX, Part I: Singlehop Networks", In Proceedings of European Wireless 2007, p. 7, Paris, France, April 2007,

[5]. Fabricio Lira Figueredo, Paulo Cardieri "Coverage prediction and performance evaliuation of wireless metropolitan area networks based on IEEE 802.16", IEEE Journal of communocation and information systems", Vol. 20, No. 3, 2005

[6]. "Digital Mobile Radio Towards Future Generatin Systems", COST 231 Final Report, http://www.lx.it.pt/cost231/final_report.htm

[7]. V. Erceg et. Al, "Channel Models for Fixed Wireless Applications", IEEE 802.16 Broadband Wireless Access Working Group, Jun 2003.