Cellular planning of 802.16e WiMAX networks

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Abstract

The world of telecommunications is in a constant evolution. In a world that gets more globalized everyday, it's up to the telecommunications to interconect people across the globe. In the past we had fixed telephones (which had a huge impact in people's lives), but now we have Internet, which allowed us to communicate with people everywhere just by clicking a mouse button, with increased efficiency and decreasing costs. Nevertheless people's demands are increasing and new technologies are required to have broadband access and new services from everywhere forcing innovation and new developments in telecommunications systems. In the last 15 years, a huge step has been taken in the mobile communications (especially since the development of GSM). A few years ago the wireless technology brought the possibility of always being connected (almost) everywhere. Nevertheless, due to speed and security limitations, the needs to develop a better mobile technology has come. This new technology as a name: WiMAX. It is expected to change the life of many persons, due to its high speed and increased security. It is based on the same architecture as a normal mobile system: one base station per cell (covering a small area) to transmit data and a mobile device to receive and transmit data at a high speed.

***Key words* — IEEE 802.16e, Modulation, Network Planning, Propagation, SUI, Telecommunications, WiMAX, Wireless.**

I. Introduction

WIMAX is a BWA (*Broadband Wireless Access*) technology, supporting high data rate. It is an evolution from Wi-Fi, since it allows higher bit-rates, has a larger coverage area and can be more economic and viable[1].

WiMAX is supported by the WiMAX Forum, that is mostly composed by hardware and telecommunications companies, whose mission is to guarantee the compatibility between devices based on the 802.16 standard. The WiMAX Forum is equivalent to the Wi-Fi alliance, responsible for the success of the 802.11 standard around the world[2].

There are different versions of the WiMAX technology. 802.16d is the fixed standard and 802.16e is the mobile standard. Currently 802.16f is under development. It is supposed to increase the bit-rate up-to 100Mbps.

This paper will explore the mathematics and physics behind 802.16e in order to design a wireless network with enough capacity to serve the city of Aveiro. Therefore, we validated our design by simulating it with a commercial simulation software. Section II explores the propagation model, section III estimates the networks needs and finally section IV presents the computer simulated network results.

II. Propagation

The two most popular propagation models in cellular planning are Hata-Okumura and Walfisch-Ikegami. Since they can only operate up to 2GHz, we need to use a different model. We select SUI (*Stanford University Interim*) which is an adequate model at frequencies of up to 4GHz. Unlike other models which take buildings into consideration, SUI uses three different ground profiles: A, B and C[3]. Profile A is suited for big losses, which includes mountains, big vegetation, etc. (but not buildings) Profile B is suited for medium losses and profile C for few losses (such as open areas). Losses in the SUI model are given by:

$$PL = A + 10\gamma \log\left(\frac{d}{d_0}\right) + Xf + Xh + s, d > d_0 \qquad (1)$$

where d is the distance between the subscriber station and the base station in meters and d_0 = 100m. The other parameters are given by:

$$A = 20\log\left(\frac{4\pi d_0}{\lambda}\right) \qquad (2)$$

$$Xf = 6\log\left(\frac{f}{2}\right) \qquad (3)$$

$$Xh = \begin{cases} -10.8\log\left(\frac{h_r}{2}\right), & \text{profile A and B} \\ -20.0\log\left(\frac{h_r}{2}\right), & \text{profile C} \end{cases} \qquad (4)$$

$$\gamma = a - b * h_b + \frac{c}{h_b}. \qquad (5)$$

h_b is the height of the base station in meters, h_r is the height of the subscriber station in meters and f is the frequency in GHz. The values of a, b, c and s are the following:

Table 1: SUI parameters

	Profile A	Profile B	Profile C
a	4.6	4.0	3.6
b	0.0075	0.0065	0.005
c	12.6	17.1	20
s	8.2	8.2	8.2

The maximum achievable distance as a function of the receiver and transmitters parameters, is:

$$d_{\max} = d_0.10^{\frac{(P_T - L_T + G_T + G_R - L_R) - S_R - (A + Xf + Xh + s)}{10\gamma}} \qquad (6)$$

where:

P_T – Transmitted power [dBm]
L_T – Transmission losses [dB]
G_T – Gain of transmitting antenna [dBi]
G_R – Receiver antenna gain [dBi]
L_R – Receiver losses [dB]
d_0 – Typically 100 [m]

and S_R is the sensitivity of the receiver, which is given by:

$$S_R = -102 + SNR + 10\log\left(\frac{8}{7} \cdot f \cdot \frac{3}{4}\right) \qquad (7)$$

where f is the bandwidth in MHz (7 in this study) and SNR is the signal-noise ratio.

III. Network design

WiMAX uses adaptive modulation [4], which means that for the same cell we can have different modulation schemes, in function of the SNR (E_b/N_0):

Table 2: adaptive modulation

Scheme	Code rate	Minimum SNR (dB)
BPSK	½	6.4
QPSK	½	9.4
	¾	11.2
16-QAM	½	16.4
	¾	18.2
64-QAM	⅔	22.7
	¾	24.4

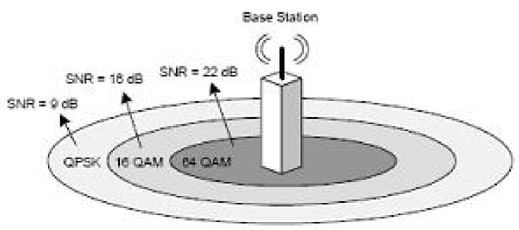

Fig. 1: adaptive modulation[5]

The capacity depends on the modulation scheme, which can be BPSK (1 bit per symbol), QPSK (2 bits per symbol), 16-QAM (4 bits per symbol) or 64-QAM (6 bits per symbol). The first step is to calculate the frequency sampling rate:

$$Fs = \frac{8}{7} \cdot BW \qquad (8)$$

where BW is the bandwidth in MHz. Then we must divide Fs by the FFT size (values are an example for a bandwidth of 7MHz, which corresponds to a FFT size of N=1024):

$$\Delta F = \frac{Fs}{N} = 7812.5 \qquad (9)$$

then the useful bit-duration:

$$Tb = \frac{1}{\Delta F} = 128\mu s \qquad (10)$$

and the total bit-duration:

$$Ts = Tb + \frac{Tb}{32} = 132\mu s \qquad (11)$$

Finally, we can calculate the bit-rate:

$$v = \frac{\frac{3}{4} \cdot FFT \cdot bits\_per\_symbol}{Ts} \cdot code\_rate \qquad (12)$$

Let us see an example for 64-QAM ¾ (6 bits per symbol):

$$v = \frac{\frac{3}{4} \cdot 1024 \cdot 6}{132\mu s} \cdot \frac{3}{4} = 26.2Mbps \qquad (13)$$

From previous equations we obtain the results in Table 3[6].

Another great feature of WiMAX is its QoS. Like other wireless technologies, WiMAX was built to work with different types of traffic, some of them requiring more bandwidth (such as video) and others requiring less bandwidth (such as e-mail). WiMAX puts a label in data packets, so that it can manage better the traffic in order to obtain better performance and offer better QoS[7]. Table 4 displays WiMAX traffic classes and their characteristics.

Table 3: bit-rates in Mbps

Bandwidth (MHz)	FFT	BPSK ½	QPSK ½	QPSK ¾	16-QAM ½	16-QAM ¾	64-QAM 2/3	64-QAM ¾
1.75	128	0.73	1.04	2.18	2.91	4.36	5.94	6.55
3.5	512	1.46	2.91	4.37	5.82	8.73	11.65	13.09
5	512	2.08	4.16	6.23	8.31	12.47	16.62	18.70
7	1024	2.91	5.82	8.73	11.64	17.45	23.75	26.18
10	1024	4.16	8.31	12.47	16.63	24.94	33.25	37.40
20	2048	8.32	16.62	24.94	33.25	49.87	66.49	74.81

Table 4: classes of QoS

Classe	Suited for	Minimum rate	Maximum rate	Latency	Jitter	Priority
Unsolicited Grant Service (UGS)	VoIP	•		•	•	
Real-Time Polling Service (rtPS)	Streaming	•	•	•		•
Non-Real-Time Polling Service (nrtPS)	FTP	•	•			•
Best-Effort (BE)	E-mail		•			•

With this information together with the results from section II, we can simulate a WiMAX network for a small city. The city will be Aveiro, Portugal (≈15km^2 of more populated area) and the software used for the simulation will be ATDI™ ICS Telecom®. Since in Portugal, WiMAX licences have a maximum bandwidth of 28MHz, we will use base stations with four sectors with 7MHz each (7·4=28), which corresponds to the greyed line in Table 3.

The following system specifications will be used:

P_T = 35dBm (transmitted power)
L_T = 1dB (transmission losses)
L_R = 1dB (reception losses)
Antenna height = 32m
2 antennas with G_T = 22dBi (transmission gain)
2 antennas with G_T = 18dBi (transmission gain)
4 antennas with G_R = 20dBi (reception gain)
Center frequency = 3.5GHz

From Table 2 we know that in order to obtain at least a scheme of 16-QAM ½, we need a SNR of 16.4dB. By using a SNR of 16.4dB in (7) we get a S_R of -78dB. By analysing Fig. 2 we can see that a base station with these characteristics will provide a 16-QAM ½ scheme or better within a diameter of 1.6km for profile A and 2km for profiles B and C. This scheme corresponds to a bit rate of 11.64Mbps (Table 3). Since the map has only 15km^2, two base stations with G_T=22dBi to cover the city itself (high density) and other two with G_T=18dBi are used to cover the suburbs. These four BS are enough to cover the whole city with good QoS.

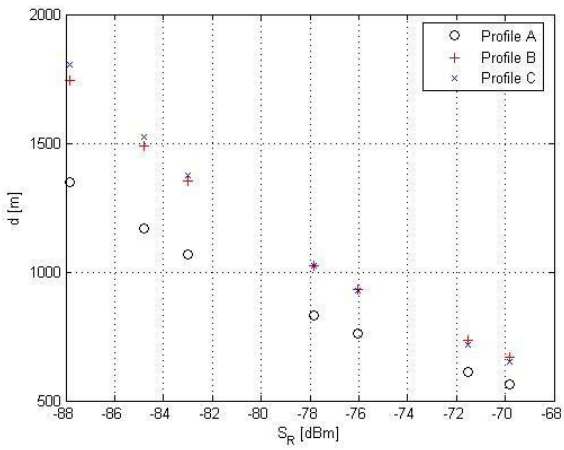

Fig. 2: Distance as a function of S_R

The next step is to define the user profile of our network. We will define a total of 1000 users, 1/3 professional (corporate) and 2/3 home users. User characteristics are presented in Table 5.

The maximum number of users that the system can handle is given by:

$$Max\_users = \frac{Bit-rate\_ofered}{user\_bandwidth/10}. \qquad (14)$$

Since a home user requires 1.33Mbps and a corporate user requires 1.11Mbps, we will have for an average offered bit-rate of 11Mbp, a maximum of 87 users per sector:

$$Max\_users = \frac{11}{\frac{2}{3}\cdot\frac{1,33}{10}+\frac{1}{3}\cdot\frac{1,11}{10}} = 87$$

Table 5: user profiles

	Scenario	VoIP	Data	IPTV	Stream	On-line gaming	Vídeo-conf.	P2P
Bandwidth required for service (Mbps)	Home (H)	0.08	4	2	0.085	0.085	0	0.5
	Corporate (C)	0.08	4	0	0	0	0.384	0
Number of times the service is used	H	7	6	2	0.5	0.5	0	3
	C	30	20	0	0	0	3	0
Average of service usage (min)	H	5	40	60	20	60	0	30
	C	2	10	0	0	0	30	0
Total time of service usage (min)	H	35	240	120	10	30	0	90
	C	60	200	0	0	0	90	0
Bandwidth required per user (Mbps)*	H	0.004	1.33	0.334	0.00278	0.00354	0	0.063
	C	0.007	1.11	0	0	0	0.048	0
Traffic classes		UGS	BE	rtPS	rtPS	rtPS	rtPS	nrtPS
%		0.436	73.824	21.965				3.775

This gives 87 users per sector. We will use a total of 13 sectors in order to support the capacity for all the users and to cover the whole city.

IV. Network simulation

The following pictures present the results of the simulation of the network going from radio coverage issues to the servives performances

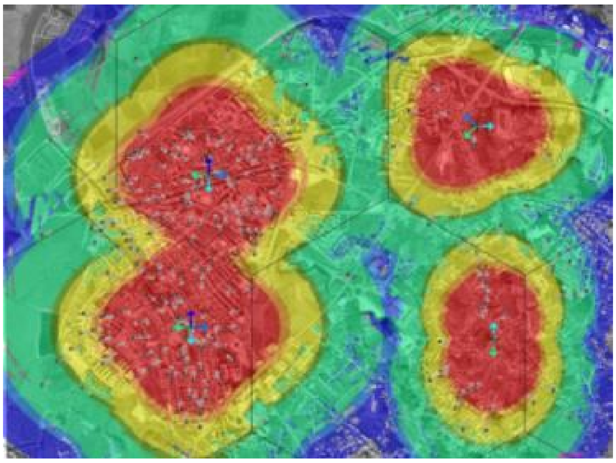

Fig. 3: Coverage

Coverage, shown in Fig. 3, is mainly determined by the antennas radiation pattern as the scenario is very flat.

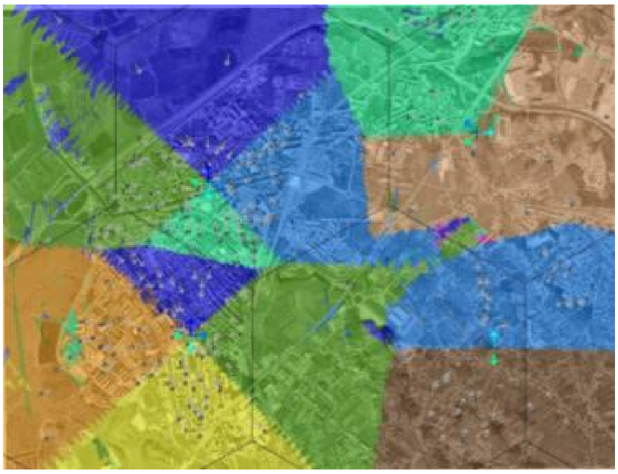

Fig. 4: Interference

The pink area represents the area where interference occurs (almost none). This represents a very well planned frequency allocation and a convenient management of a high number of sectors. Although this is a very satisfactory result, if the number of base stations increases significantly, interference will probably be an issue. In Fig. 5, we can see the places in the map where handovers are more likely to occur:

Fig. 5: Handover areas

The pink area represents potential handovers: that is areas between sectors in the same BS or sectors of adjacent BS.

Table 6 displays the coverage in terms of percentage:

Table 6: Coverage area per modulation scheme

QPSK ¾	16-QAM ½	16-QAM ¾	64-QAM 2/3	64-QAM ¾
32.00%	4.74%	17.41%	4.94%	22.53%

IV. Conclusions

The theoretical results of the coverage are very similar to the experimental ones, which confirms that the planning and the simulation agree very well[9]. We can see a cellular network with good coverage, high speed and almost no interference.

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