Technological Solutions for WiMAX Network Planning

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***Abstract*— The planning of broadband access network topologies poses several challenges, as different access technologies may have different bandwidth, robustness, and installation cost requirements, which should be jointly considered in the conception of the overall network topology, to properly match the end users requirements.**

This paper addresses the planning of wireless networks using IEEE 802.16, for a set of different user profiles, different services and requirements, and different scenarios (residential, business, mixed) with different terrains. An application has been developed to design and plan IEEE 802.16 wireless networks. The results show that there are several possibilities of solutions to satisfy the needs of specific scenarios, whether the desired solution should have better coverage area or better capacity. The planning tool enables the user to change the solution to better fit for the deployment needs.

I. INTRODUCTION

The communication industry has suffered massive evolution throughout the past years. This evolution pursues one clear goal: the possibility to establish mobile broadband connections anywhere and anytime. In this context, the new WiMAX (Worldwide Interoperability for Microwave Access) technology appears as a possibility to reach this goal.

WiMAX is the commercial name of IEEE 802.16, and its fixed variant is the result of the IEEE802.16-2004 [1]. It describes a point-to-multipoint broadband wireless access standard for systems operating in the frequency range of 2-11 GHz, and 10-66 GHz. This standard includes descriptions for both the Medium Access Control (MAC) and the physical (PHY) layers, in order to guarantee multi-vendor interoperability. The standard describes different modulation schemes (Single Carrier - SC, Orthogonal Frequency Division Multiplexing - OFDM and with Multiple Access - OFDMA) with related frame structures, but only the OFDM is certified by WiMAX Forum for fixed applications.

The 256-subcarrier OFDM physical layer is defined for fixed WiMAX. Of these 256 subcarriers, 192 are used for data, with 56 nulled for a guard band and 8 used as permanent pilot symbols. Subcarriers can be modulated in an adaptive way, using BPSK, QPSK, 16-QAM and 64-QAM. The idea behind Adaptive Modulation Coding is to dynamically adapt the modulation and coding scheme to the channel condition so as to achieve the highest spectral efficiency at all the times. In this way, the system will always try to use the most out of what the channel allows, depending on its conditions. The choice of the modulation between low efficiency ones (like BPSK 1/2) to high efficiency ones (like 64-QAM 3/4) depends on the Signal to Noise Ratio (SNR): with worst signal conditions, a more robust modulation scheme is used. The choice of the best modulation scheme has a very important role on the system capacity: the more robust to interference the modulation is, the more its capacity gets reduced.

This paper presents a study of possible implementations of WiMAX technology and a planning tool that determines the required topology and configuration considering the required system capacity and coverage, taking into account several scenarios with specific user and service profiles and requirements. The developed application simplifies, automates and generalizes the whole planning process. The results show that there are several possibilities of solutions to satisfy the needs of specific scenarios, whether the desired solution should have better coverage area or better capacity. The planning tool enables the user to change the solution to better fit for the deployment needs.

This paper is organized as follows. Section 0 presents the characteristics of IEEE 802.16 technology and the calculation of important parameters, such as the capacity, path loss, cell coverage and parameters that impact cell planning. Section III introduces several scenarios for users and service requirements, and section 0 analysis possible deployment solutions. Section 0 presents the tool for network planing and dimensioning and section 0 presents the respective results. Finally, section 0 depicts the final conclusions.

II. IEEE 802.16 AND ITS RADIO ACCESS TECHNOLOGIES

A. Fixed WiMAX Capacity

It is very important to know the PHY layer of IEEE 802.16 in order to understand its influence in the total capacity of a WiMAX system. The bandwidth of the channel is a very important factor, as it restrains the raw capacity of the channel.

In OFDM, the occupied spectrum is broken into subcarriers. Each data carrier is modulated over a symbol time so that all subcarriers are orthogonal between each other. The capacity of each one depends on the modulation order, which can be BPSK (1 bit per subcarrier), QPSK (2 bits), 16-QAM (4 bits) and 64-QAM (6 bits per subcarrier). The sampling spectrum is obtained through

$$Fs = Floor(n \times BW/8000)*8000 \quad (1)$$

where n is the sampling factor, which depends on the channel Size, and BW is the capacity in Hz. The spacing between the 256 subcarriers is given by $\Delta f = Fs/256$. As said before, only 192 subcarriers are used for data. In order to find the raw capacity of the channel, the symbol time is required. It is given by

$$Ts = 1/\Delta f \times G \times (1/\Delta f) \quad (2)$$

where $G=1/2^m$, where m may assume the values {2, 3, 4 ,5}.

The raw capacity of the channel is given by

$$C_{raw} = 192 \times (k/Ts) \quad (3)$$

where k represents the modulation order.

The useful channel capacity depends now on the Forward Error Correction (FEC) technique, which is used by WiMAX to easily detect and correct transmission errors. It introduces redundant bits, reducing the overall capacity. So, the useful capacity of the system is given by $C=C_{raw} \times OCR$, where OCR is the coding ratio. The different channel sizes considered in this work were 3.5, 5, 7, 10, 14 and 20 MHz. Table I shows the different capacity values calculated for each modulation and bandwidth.

TABLE I - Useful Channel Capacity for Each Modulation and Channel Size

Modulation	Bandwidth (MHZ)					
	3.5	5	7	10	14	20
BPSK 1/2	1,45	2,08	2,91	4,16	5,82	8,31
QPSK 1/2	2,91	4,16	5,82	8,31	11,64	16,62
QPSK 3/4	4,36	6,23	8,73	12,47	17,45	24,94
16-QAM 1/2	5,82	8,31	11,64	16,62	23,27	33,25
16-QAM 3/4	8,73	12,47	17,45	24,94	34,91	49,87
64-QAM 2/3	11,64	16,62	23,27	33,25	46,55	66,49
64-QAM 3/4	13,09	18,7	26,18	37,4	52,36	74,81

B. Path Loss

The propagation model adopted is the SUI (Stanford University Interim). It is suited for the 2.5 and 3.5 GHz frequency bands. It considers 3 different terrain types (A, B and C). Type A is associated to maximum path loss, with highly mountain terrain and moderate to heavy tree densities. Type C is a mostly flat terrain with light tree densities. Type B is a terrain with intermediate path loss conditions. The path loss equation is given by

$$PL = 20\log_{10}\left(\frac{4\pi d0}{\lambda}\right) + 10\gamma\log_{10}\left(\frac{d}{d0}\right) + X_f + X_h + s \quad (4)$$

$$\gamma = a - bh_b + \frac{c}{h_b} \quad (5)$$

$$X_f = 6.0\log_{10}\left(\frac{f}{2}\right) \quad (6)$$

$X_h = -10.8\log_{10}\left(\frac{h_r}{2}\right)$ (7.1), used for types A and B terrain.

$X_h = -20\log_{10}\left(\frac{h_r}{2}\right)$ (7.2), used for type C terrain

where s (s Є [8.2,10.6] dB) is the lognormal statistical distributing factor used to calculate the fading due to obstacles, d is the cell coverage, γ is the exponent of load factor, X_f is the correction factor for the operation frequency, and X_h is the correction factor for the receiver antenna height. The parameters f and h_r are given in GHz (frequency) and meters (height of the receiver), respectively. Table II shows the values that parameters a, b and c assume according with their terrain type.

TABLE III - SUI Model’s Characteristic Values

Parameters	Type of Terrain		
	A	B	C
A	4.6	4.0	3.6
b (m^{-1})	0.0075	0.0065	0.005
C(m)	12.6	17.1	20

C. Cell Coverage

In order to calculate the cell coverage and perform a link budget, we need to first calculate the received power, which is given by formula (8).

TABLE III - SUI Model’s Characteristic Values

	Parameters
$P_R = P_T + G_T + G_R - L_S - PL$ (8) [4]	P_R – Received Power [dBm]
	P_T – Transmitted Power [dBm]
	G_T – Transmit Antenna Gain [dBi]
	G_R – Receiver Antenna Gain [dBi]
	L_S – System Loss (Transmit Feeder Loss + Receiver Feeder Loss)[dB]
	PL– Path Loss [dB]

We now consider S_R as the receiver sensitivity [dBm]. In order for the system to work correctly, the receiver sensitivity must be lower than the received power, $P_R \geq S_R$ (9).

If we relate the formulas (9) and (8), then $PL = P_T - L_S + G_R + G_T - S_R (7)$. With (4) we can isolate *d*, and we will get the following expression for the cell coverage, *d*:

$$d = d0.*10\wedge\left[\frac{\left(P_T - L_S + G_R + G_T - S_R - X_f - X_h - s - 20\log\left(\frac{4\pi d0}{\lambda}\right)\right)}{10\gamma}\right] \quad (10)$$

Expression (10) gives the maximum distance each modulation can reach, since SR (receiver sensitivity) is different for each modulation. SR can be calculated through the formula in (11) [5]. Table V presents the different values of SR for each modulation and bandwidth.

$$S_R = -102 + SNR(Rx) + 10\log(Fs * \left(\frac{N}{N_{FFT}}\right) * \left(\frac{N_{subchannels}}{16}\right) \quad (11)$$

With N=192 and N_{FFT}=256, *SNR(Rx)* is defined in the standard (Table IV). Finally, S_R is presented in Table V where different modulation schemes and bandwidth frequencies are considered.

TABLE IIIV - SNR(Rx) Defined in the IEEE802.16

Parameters	**SNR(Rx) [dB]**
BPSK 1/2	6.4
QPSK 1/2	9.4
QPSK 3/4	11.2
16-QAM 1/2	16.4
16- QAM 3/4	18.2
64-QAM 2/3	22.7
64-QAM 3/4	24.4

TABLE V - Receiver Sensitivity for each Modulation and Bandwidth

Modulation	**Bandwidth (MHZ)**					
	3.5	**5**	**7**	**10**	**14**	**20**
BPSK 1/2	-96,85	-95,3	-93,84	-92,29	-90,83	-89,28
QPSK 1/2	-93,85	-92,3	-90,84	-89,29	-87,83	-86,28
QPSK 3/4	-92,05	-90,5	-89,04	-87,49	-86,03	-84,48
16-QAM 1/2	-86,85	-85,3	-83,84	-82,29	-80,83	-79,28
16-QAM 3/4	-85,05	-83,5	-82,04	-80,49	-79,03	-77,48
64-QAM 2/3	-80,55	-79,0	-77,54	-75,99	-74,53	-72,98
64-QAM 3/4	-78,85	-77,3	-75,84	-74,29	-72,83	-71,28

D. Parameters that Impact Network Planning

There are several parameters that must always be considered within the cellular planning process.

The available spectrum is one of the most important one, because it has influence on many other factors. It is generally ruled by an entity, which only makes one part available for the operators. In this way, the scarcity of spectrum can be a huge limitation on the planning of a wireless network. It influences the choice of the size of the channels, as well as other important issues, such as frequency planning (frequency reuse and sectoring).

Other important parameter concerns the geographical conditions of the deployment area, along with the heights of antennas. As was previously referred, the density of obstacles that exist on the terrain have direct impact on the path loss, which will affect the reach of the cell. On the other hand, the area that we need to cover is also very important, because the cell size influences its capacity.

Other factor that cannot be ruled out is the density of users in the deployment area. In fact, there must be a prediction of the amount of traffic that these users will need, in order to satisfy their needs with the existing technology. The next section will address different user and services requirements, with respect to different scenarios envisioned.

III. SCENARIOS: TYPES OF USERS AND SERVICES

In order to predict the amount of traffic that the users will require, some scenarios were idealized. We considered a reasonable set of services to represent possible scenarios: VoIP, Data, IPTV, Media Stream, Online Gaming, Peer2Peer and Videoconference. There are 2 categories for the services: Residential and Business. This is shown in Table VI, along with each service's required capacity. In the case of P2P and Data, we assumed reasonable values. All the others were based on real values. The mapping between services and categories (business or residential) was performed to create examples of different scenarios. However, this mapping is just an example, and other mappings could be envisioned.

TABLE VI - Requisites for Each Service

Services	**Required Capacity (Mbps)**	
	Residential	**Business**
VoIP	0.080	0.080
Data	1.000	2.000
IPTV	2.000	
Media Stream	0.200	
Online Gaming	0.085	
P2P	0.500	
Videoconference		0.384

Now that the services are characterized, we are able to create the scenarios. We have chosen 4 scenarios, with different needs and geographic characteristics, as shown in table VII. These scenarios try to capture the several mappings of different services, terrains and users density.

TABLE VII - DIFFERENT SCENARIOS AND THEIR CHARACTERISTICS

Different Scenarios		Terrain	Services
Scenario A	Residential	Type C	VoIP, Data, IPTV
Scenario B	Residential	Type B	VoIP, Data, IPTV, Media Stream, Online Gaming, P2P
Scenario C	Business	Type B	VoIP, Data, Videoconference
Scenario D	Mixed	Type A	All services

The next step is to allocate values to periodicity and duration of the calls for each type of service. That way, the traffic can be characterized through traffic intensity. We consider that calls arrive to the system according to a Poisson process with an arrival rate of λ and their duration time is exponentially distributed with average $1/\mu$. [3] This way, traffic intensity is given by $\rho=\lambda/\mu$. This is shown in table VIII. Figure 1 shows the required capacity for each scenario, with the variation of the number of users. When we sum the capacity of all services and then multiply it with the number of users, we obtain the total required capacity of the system for the considered scenario (table VIII).

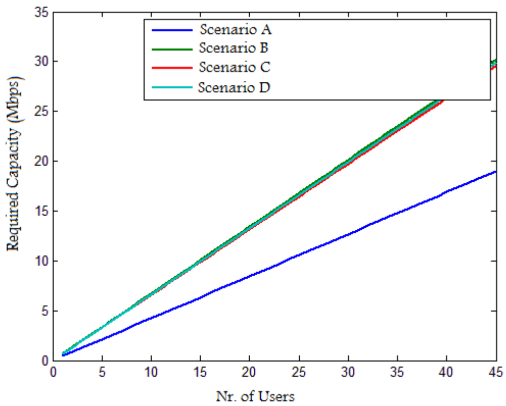

Fig. 1 Graph that describes the required capacity as a function of the number of users.

IV. ANALYSIS OF POSSIBLE DEPLOYMENT SOLUTIONS

Now with concrete examples of requirements for each scenario, it is possible to provide solutions to deploy a WiMAX network capable of serving each scenario.

First, it is required to get the maximum distance each modulation is capable of reaching, considering a certain size of the channel, knowing its capacity (Table I) and receiver sensitivity (Table V). The area of each modulation is obtained through the formula for the area of the hexagon, $A_i = 3\frac{\sqrt{3}}{2}*(d_i^{\,2} - d_{i-1}^2)$. That way, each modulation covers only a percentage of the total area of the cell (see Fig. 2). Knowing the capacity of each modulation and the percentage of area it covers, the total capacity of the cell is given by

$$C= \Sigma(C_{Moodulatin\ i}*(Area_{Modulation\ i}/Area_{Total})) \quad (12).$$

This method is similar for all the scenarios, and therefore we will consider only scenario A in this phase.

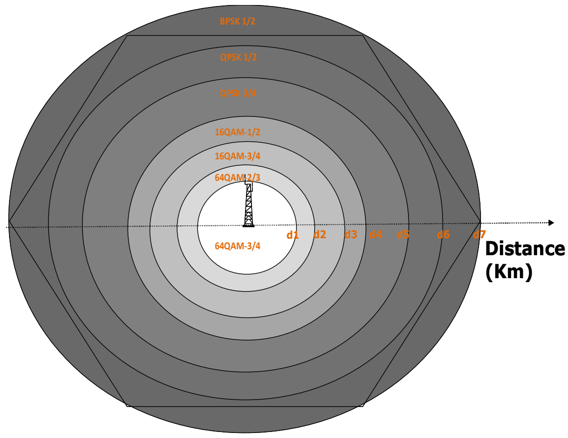

Fig. 2 Sketch of a WiMAX cell

For scenario A, some considerations concerning the deployment were taken, whose parameters are presented in table IX. The results are obtained considering a system with one sector and three sectors. Then, all the calculation

TABLE VIII

Utilization for Each Scenario and Traffic Intensity

		VoIP	**Data**	**IPTV**	**Media Stream**	**Online Gaming**	**P2P**	**VideoConference**
Number of utilizations	A	5,000	4,000	1,000	0,000	0,000	0,000	0,000
	B	7,000	6,000	2,000	0,071	0,012	0,024	0,000
	C	30,000	20,000	0,000	0,000	0,000	0,000	3,000
Average length of each utilization (min)	A	10,000	30,000	90,000	0,000	0,000	0,000	0,000
	B	5,000	40,000	60,000	30,000	60,000	30,000	0,000
	C	2,000	10,000	0,000	0,000	0,000	0,000	60,000
ρ (λ/μ)	A	0,069	0,167	0,125	0,000	0,000	0,000	0,000
	B	0,049	0,333	0,167	0,003	0,001	0,001	0,000
	C	0,083	0,278	0,000	0,000	0,000	0,000	0,250
Capacity	A	0,00556	0,16667	0,25000	0,00000	0,00000	0,00000	0,00000
ρ*LB	B	0,00389	0,33333	0,33333	0,00060	0,00008	0,00050	0,00000
(Mbps)	C	0,00667	0,55556	0,00000	0,00000	0,00000	0,00000	0,09600
	D	0,01056	0,88889	0,33333	0,00060	0,00008	0,00050	0,09600

results are presented in table X.

TABLE IVX - Simulation Values for Scenario A

Parameters	Value]
BW	3.5 MHz
P_T	35 dBm
G_T	16dBi
G_R	18 dBi
h_R	4 m
h_b	50 m
L_s	1.1 dB

TABLE X - Simulation Results for Scenario A

Modulation	Dist [km]	Covered Area [km^2]	Capacity 1 Sector [Mbps]	Capacity 3 Sectors [Mbps]
BPSK 1/2	8,20	53,85	0,45	1,35
QPSK 1/2	6,82	23,85	0,40	1,20
QPSK 3/4	6,11	45,77	1,14	3,42
16-QAM 1/2	4,44	10,27	0,34	1,02
16-QAM 3/4	3,97	17,41	0,87	2,61
64-QAM 2/3	3,01	4,46	0,30	0,90
64-QAM 3/4	2,71	19,08	1,43	4,29
Total		174.69	4,93	14,79

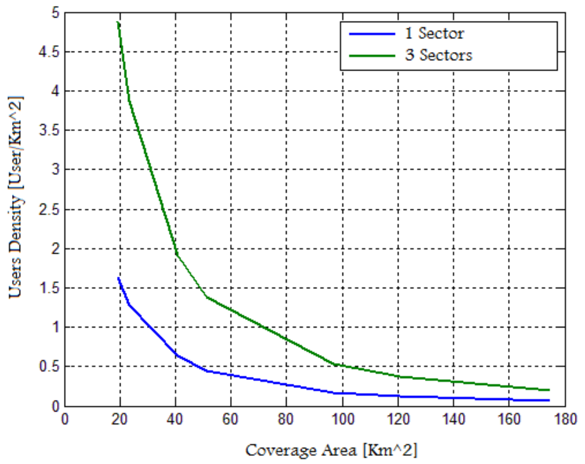

Fig. 3 Graph of the density of users that can be served with the variation of the coverage area, for scenario A.

After reaching the results of the table X, we can reduce the coverage area of the cell by deactivating the modulations that provide larger coverage area. That way, there is a gain in capacity, but a decrease in the maximum distance the cell can reach. That fact is obvious in figure 3, where the smallest coverage area can serve the larger density of users.

We can conclude that cellular planning is a sensitive matter that takes into account many issues. As a matter of fact, each case has to be treated in such a way that it can provide the best solution in terms of capacity and coverage to better serve the needs of the scenario. The next section presents a tool that is able to provide the planning of WiMAX cellular for any scenario, services and users requirements.

V. TOOL FOR NETWORK DIMENSIONING

All the calculations made so far involved several platforms, in a non automated way. In this context, a tool is needed to simplify, automate and generalize the whole process. To this purpose, an application was created to fulfill this need, making all the calculations described in this paper in a very fast and accurate way, with a user-friendly interface, and enabling the support of any envisioned scenario.

The tool was developed dividing the process of network planning into three different phases: Dimensioning, Planning and Optimization. In the first phase, the user introduces important data into the application. The data refers not only to characteristics about the network traffic, but also important information that refers to the physical dimensioning of the cell. In the second phase, all data introduced is manipulated. At first, the traffic is characterized, in terms of capacity requirements and radio channel aspects. Then, the cells are planned, combining all the constraints introduced by the user. In the last phase, the user is given a first solution, which depends mainly on the number of sectors and size of the channels: the application chooses the suitable option that has less number of sectors and uses the smaller channels. This choice is made based on economical issues, since many sectors result in a most expensive deployment. On the other hand, the smaller the channels are in terms of bandwidth, the more scalable they are, because it is possible to use the available spectrum in a more efficient way. In this phase, the user can adjust the results, and try different solutions compared to the one presented by the application. The results are automatically presented. Figure 4 schematizes the flowchart of the application, while table XI shows the adopted strategy in the implementation of the tool.

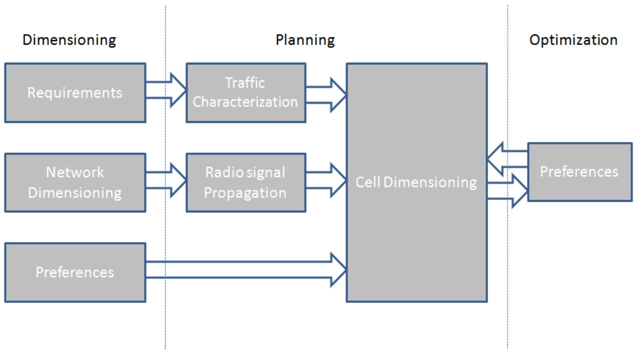

Fig. 4 Design flowchart of the developed application

VI. RESULTS

This section presents results obtained with the developed application. We will demonstrate a scenario very similar to scenario D. The traffic requirements are calculated following the values introduced as shown in figure 5.

TABLE XI - Strategy Adopted for the Implementation of The Tool

Extraction of Values	The values introduced by the user are stored in variables
Calculation of Traffic Intensity	According to those values, the traffic intensity (ρ) for each service is calculated.
Calculation of Capacity for Each Service	Knowing the traffic intensity for each service, the capacity for each service is now obtained. $C_{Service}=\rho*Requirement_{Service}$
Calculation of Distances	Through the receptor sensitivity, the various distances for each modulation and each bandwidth are calculated through (11).
Calculation of Area and number of Users	The area is calculated, allowing the determination of the number of users (*N*), because one of the data inputs of the application is the users' density.
Calculation of the required capacity for the considered scenario	The total required capacity is now obtained. $C_{Req} = N*\Sigma (C_{Services})$
Calculation of the Cell Capacity	The calculation of the cell capacity is performed through (12).
Algorithm for the Best Choice	The application performs the calculation for the several options available and chooses the one that requires less number of sectors and smaller bandwidth channel.
User Adjustements	The user may adjust the values, by selecting different cell ranges and/or different channel sizes. The results are automatically presented on the screen.

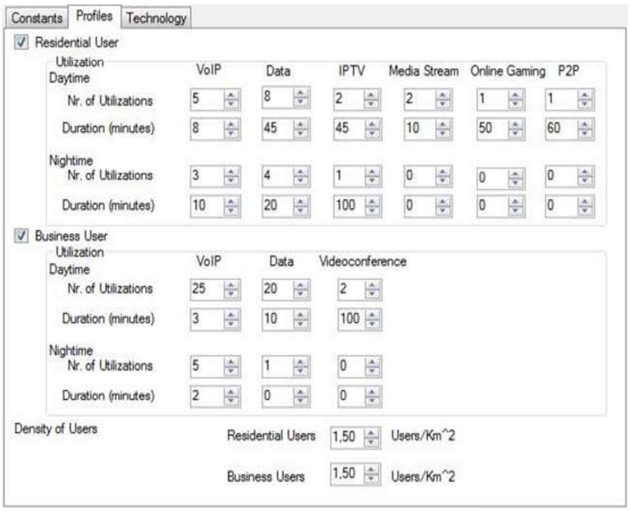

Fig. 5 Using the developed application: the user profiles on the considered scenario

The application calculates the option of figure 6 as the best choice with only 1 sector and a smaller distance of 1.68 Km. However, in figure 7, we show a different option, after some manual adjustments, with 3 sectors and a larger distance of 2.33 Km. Both these solutions are able to comply with the scenarios/services/users requirements. There is a huge variety of solutions to satisfy the needs of this deployment, whether the desired solution has better coverage area, or better capacity. The user now decides the best fit for the deployment needs.

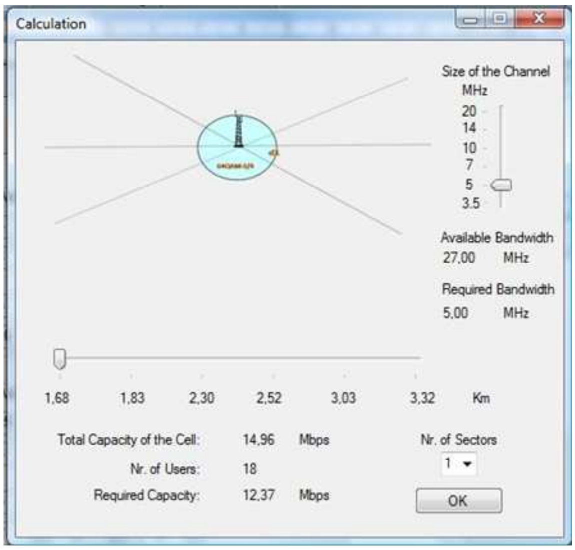

Fig. 6 Using the developed application: possible result obtained

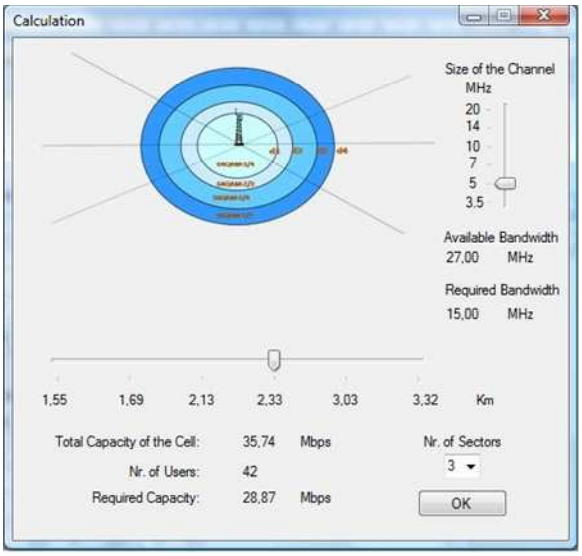

Fig. 7 Using the developed application: other possible result obtained

VII. CONCLUSIONS

Through the work developed in this paper, we conclude that it is possible to deploy a WiMAX network for each considered scenario capable of satisfying the needs of its users and services. There are several factors that have great influence in the performance of the system, which alerts to the need of a careful planning. Some important parameters that affect cellular planning were presented, as well as their effect. With the obtained results we can conclude that there are several possible solutions to deploy a WiMAX network. In this context, the network engineer must choose the one that gives the balance between economical issues, coverage area and user needs.

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