PLANNING OF AN IEEE 802.16e NETWORK FOR EMERGENCY AND SAFETY SERVICES

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Abstract

An overlaid Wimax cellular structure is proposed for emergency and safety services, with micro-cells covering urban hotspots over a macro-cellular structure. In the region of Beira Interior the process of cellular planning has to account for carrier-to-noise-interference ratio. Sectorisation is used in order to reduce reuse patterns and increase system capacity, while cell overlay is proposed to overcome coverage problems in large towns and cities. Geographic Information Systems tools are considered for Line-of-Sight discovery, and ~75% of LoS coverage is guaranteed in the city of Covilhã. The point-to-point component is also being incorporated in the planning tool. By comparing the 3.5GHz and the 5.8GHz bands one concludes that it is possible to use lower values of the antenna gains in the first case.

1 Introduction

Wimax (Worldwide Interoperability for Microwave Access) is becoming more and more popular for both point-to-point and point-to-multipoint outdoors communications. While IEEE 802.16-2004 standard covers the fixed market, IEEE 802.16e is covering the mobile segment, and has an enormous potential in providing truly mobile broadband applications.

In Portugal, as there is no digital public emergency and safety wireless communications system yet, e.g., TETRA (TErrestrial Trunked RAdio), the introduction of Wimax gains special interest. Via a service-oriented approach, where the needs of fireman, policy, ambulances, etc are taken into account, it is possible to establish a framework for an initial planning of a wireless metropolitan area network, where users will have access to interactive voice, data, video and multimedia communications. This will be enabled by using innovative terminals, like PDAs or Tablet PCs, which will combine voice with other type of communications, including image and video. One example can be the communication of real-time image from the fire scene to the command centre. During Summer time, simultaneous fires in forests are a persistent calamity, and the authorities lacks access to real-time information on the evolution of fires in order to coordinate fire brigades. Another example is the surveillance of commercial streets by using real-time video.

In the context of Universities and Hospitals other applications are e-learning and e-health; hence, our work addresses an overlaid cellular structure, with micro-cells covering urban hotspots over a macro-cellular structure, covering the entire region of Beira Interior, Portugal, Fig. 1. While the macro-cellular structure is mainly dedicated to emergency and security public services, the urban micro-cells will also support e-learning and e-health services, among others.

Our starting point is mainly based in the experience acquired in the development of two cellular planning tools: a cellular planning tool for outdoor mobile broadband systems operating at the millimetre wavebands, where BSs (base stations) are placed below the level of rooftops, typically mounted at lampposts [10], and a cellular planning tool for IEEE 802.11 indoor Wireless LANs [9]. In these tools, the determination of LoS (Line-of-sight) is based into algorithms for polygon visibility, i.e., visibility chains.

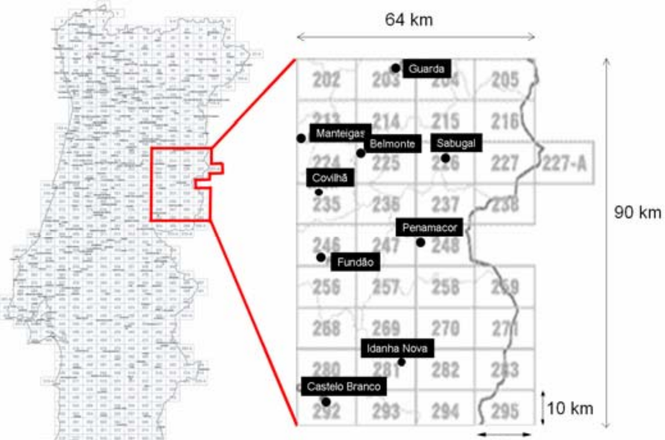


Figure 1: Beira Interior, Portugal.

This work intends to develop the concept and tools to automate the Wimax planning process having the digital information of the terrain into account. The point-to-point component is also being incorporated through techniques for the design of microwave radio links and relays [2].

Section 2 presents aspects of cellular planning, and discusses the variation of carrier-to-noise-interference ratio with different parameters, the use of sectorisation and cell overlay, and the consequences of the different propagation exponents/environments in system capacity. In Section 3 the potentialities of Geographic Information Systems are explored for LoS discovery in the city of Covilhã. Section 4 presents details on the design of the Wimax point-to-point component by means of radio link dimensioning techniques. Finally, conclusions are presented in Section 5.

2 Cellular Planning

Over the region of Beira Interior, with an area of $64{\cdot}90=5760\text{km}^2$, the process of cellular planning has to simultaneously account for carrier-to-noise and carrier-to-interference constraints. A simple propagation model [7] is adapted from the Friis free space equation, where different propagation environments are modelled by replacing the propagation exponent 2 by different propagation exponents, γ, which vary from $\gamma=2$, in free space, e.g., rural areas, to $\gamma=3$, in urban areas (no shadowing), and $\gamma=4$, in shadowed urban areas [7]. In free space propagation conditions another alternative could be the SUI (Stanford University Interim) model [1]. It is approximately equivalent to the Friis free space adapted equation (with $\gamma=2$) but more optimistic.

The number of macro-cell necessary to cover the area under study is 35 and 62 cells, approximately, for coverage distances R=8 and R=6km, respectively. They are obtained by dividing the total area by the area of each hexagonal cell. The cellular planning tool will achieve results as in Fig. 2, where micro-cells with coverage distance $R/2$ are also included for the case of cell overlay. The analysis of the carrier-to-noise ratio for different propagation environments shows the limitations on coverage for f=3.5GHz, Fig. 3. The effect of rain attenuation is included. By considering G_t+G_r=25dBi, P_t=0dBW, a bandwidth of 5MHz, and a noise factor of 3dB (where G_t and G_r are the transmitter and reception antenna gains, respectively, and P_t is the transmitter power), Fig. 3 shows that, for values of $(C/N)_{min}$ of the order of 6-8dB, it is only possible to achieve $C/N>(C/N)_{min}$ with $\gamma=2$ and $\gamma=3$, although for $\gamma=3$ this is only achievable up to d=4km (note that, for higher order modulations, typical values for $(C/N)_{min}$ are of the order of 15-16dB [3]). Hence, while in open space, e.g., rural areas, coverage is not a limitation, in urban areas, high coverage distances will be impossible, and micro-cells with coverage distances, R, up to 3-4km have to be used.

A proposal to overcome this limitation is to overlay micro-cells to the macro-cellular structure. Besides, in urban areas a careful choice of the placement and height of the BSs transmitter antennas is needed in order to ensure a high percentage of LoS within the cells, and guarantee that the propagation exponent is of the order of $\gamma=3$ (maximum).

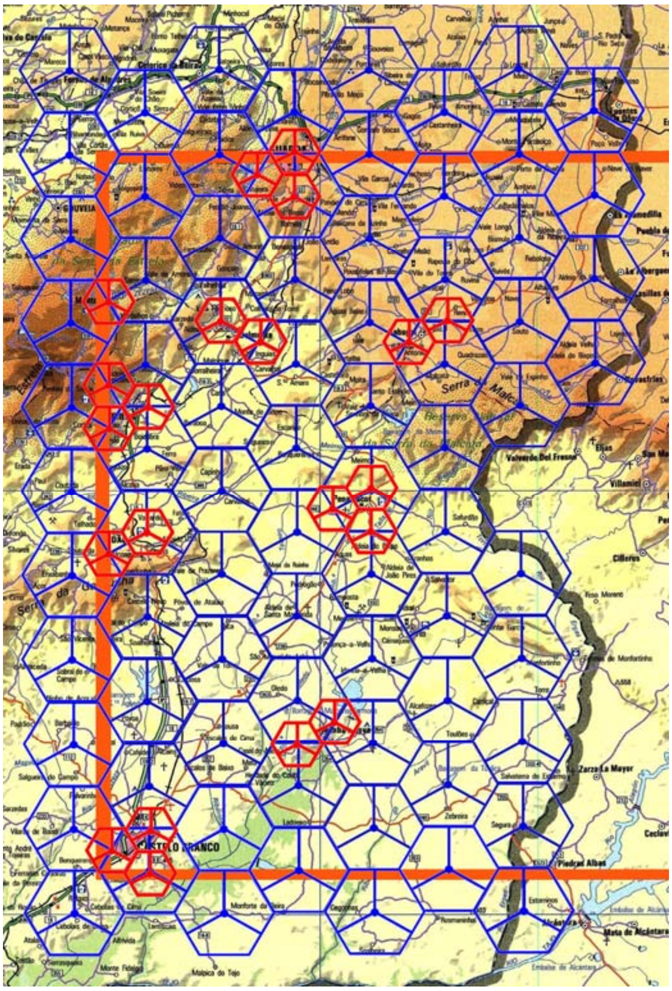


Figure 2: Cellular layout for the area under study, R=6km.

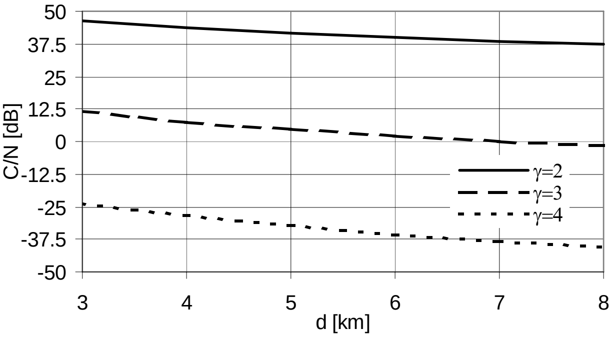


Figure 3: Carrier-to-noise ratio for different environments.

Regarding co-channel interference [7], with this simple propagation model the carrier-to-interference ratio is

$$C/I = \frac{1}{2(q-1)^{-\gamma} + 2q^{-\gamma} + 2(q+1)^{-\gamma}}, \qquad (1)$$

where $q=D/R=\sqrt{3k}$, only depends on the ratio between the coverage distance, R, and the reuse distance, D, or, alternatively, on the reuse pattern, k. Considering omni-directional antennas [7], for $\gamma=2$, one needs to use a reuse pattern, k, higher or equal to 12 to overcome $(C/I)_{min}$=6-8dB, Fig. 4.

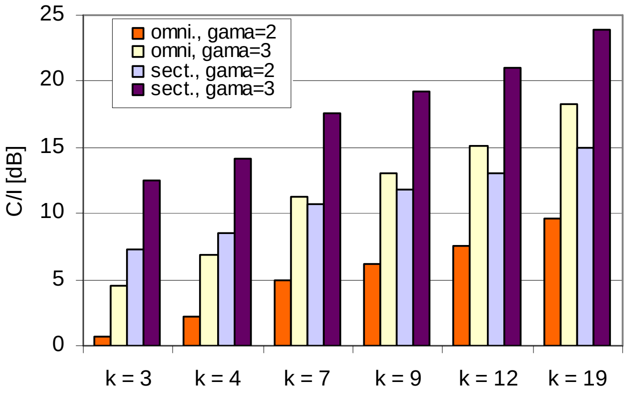


Figure 4: Carrier-to-interference ratio with omni-directional and sectorial antennas, in different environments.

If 120º sectorial antennas are used, the carrier-to-interference ratio is obtained in a different way [5]

$$C/I = \frac{1}{(q+0.7)^{-\gamma} + (q-0.22)^{-\gamma}} \,. \qquad (2)$$

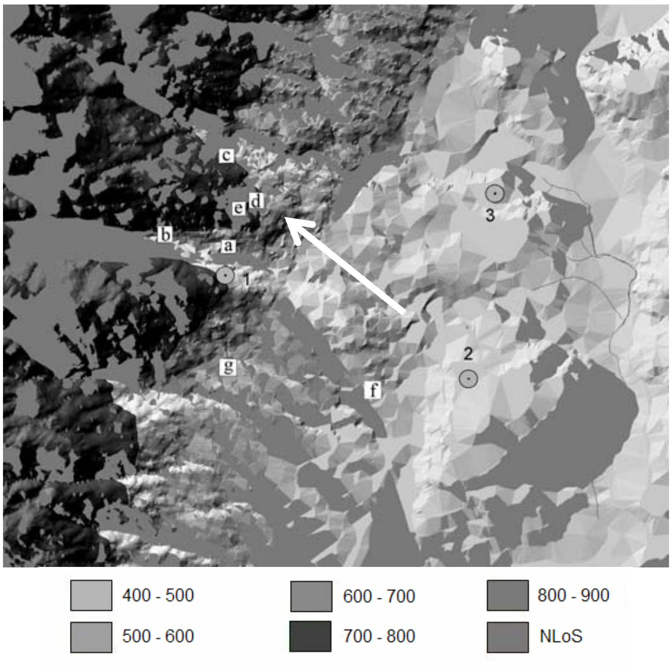
Better results are achieved, Fig. 4, and k=3-4 is sufficient. However, for higher order modulations, a reuse pattern of at least 19 would be needed to overcome $(C/I)_{min}$ = 15-16dB.

In urban areas with no shadowing, γ=3 is considered. A minimum reuse pattern k=4-7 is achieved with omni-directional antennas, while k=3 is enough with sectorial ones. So, sectorisation will be used to reduce the reuse pattern to acceptable values, and cell overlay is suggested to overcome coverage problems in main towns and cities, Fig. 2. Besides, functionalities of optimisation/choice of high altitude position for BSs (base stations) have to be included in the tool in order to guarantee LoS conditions over the entire cell.

3 Micro-cellular LoS Dimensioning

In large towns and cities, in order to have higher capacity and a better coverage micro-cells with half of the coverage distance, $R/2$, will be overlaid with the macro-cellular structure. As the propagation conditions degrade with the existence of shadowing, namely because of urban obstacles and earth relief, a higher propagation exponent has to be considered. Hence, the location and height of base stations have to be carefully chosen through LoS discovery, Fig. 5, and the tool incorporates GIS (Geographic Information Systems) functionalities for the choice of the best placement of transmitters, including their height and orientation angle.

For a given coverage area and cell coverage (radius), and by using digital terrain models/features, the process of finding the LoS region "seen" by each BS (BSs 1, 2 and 3 in Fig. 5) is being automated by using ArcGIS 9.0 [6] (3D Analyst extension). The white arrow represents increasing altitudes, from ~400m to ~850m. Some main buildings of University of Beira Interior (UBI), which are spread among different locations, and other public services are marked (a-f). In the area under study, and after some iteration, if the zones with no pedestrian or car access are discounted, one obtains a LoS coverage area of ~75%, Fig. 5.



a – UBI, main building
b – UBI, Faculty of Engineering
c – UBI, Faculty of Social Sciences
d – City Council
e – Police Station
g – Health Centre
f – Hospital

Figure 5: LoS areas by using digital terrain information, city of Covilhã (NLoS areas are represented by grey spots).

In these LoS zones, a propagation exponent around γ=3 is guaranteed. From the local experience, there are large smoke clouds with tens of kilometres while huge fires in forests are occurring. Although the specific attenuation from smoke is not being considered, it will be important to consider its impact in the design process of a wireless communication system for public emergency and safety services, and further research is needed to determine these values.

4 Design of Point-to-point Radio Links

Due to the complementarities between fixed and mobile IEEE 802.16, and also because of the nowadays unavailability of IEEE 802.16e equipment, it is essential to incorporate the fixed/portable Wimax component into the design process of the cellular planning tool. Besides, Wimax can support the backhaul infrastructure of fixed and wireless Local and Metropolitan Area Networks, which will be very useful for emergency and safety services. The MobileMAN (Mobile IP for Broadband Wireless Metropolitan Area Networks) project involves the design of a point-to-point radio link between the premises of HSF (Health Science Faculty) of University of Beira Interior in Covilhã and the Hospitals of Castelo Branco and Guarda, two nearby important cities, by using a relay in Serra da Gardunha, a mountain strategically chosen, Fig. 6. Besides their usefulness for demonstration and research purposes, these radio links will allow for a better cooperation between HSF and Hospitals, improving the quality of services given to patients, and an easier access to e-learning contents, among other, by professors, students, doctors, nurses and other professionals.

Figure 6: Wimax radio links with a relay.

In the link between Covilhã and Castelo Branco, for the locations chosen to the end stations, the first Fresnel ellipsoid is totally unobstructed in both hops (Covilhã-Gardunha, 22.5km, and Gardunha-Castelo Branco, 28.5km), Fig. 7, and the design involves techniques similar to the dimensioning process of digital microwave radio links with a repeater.

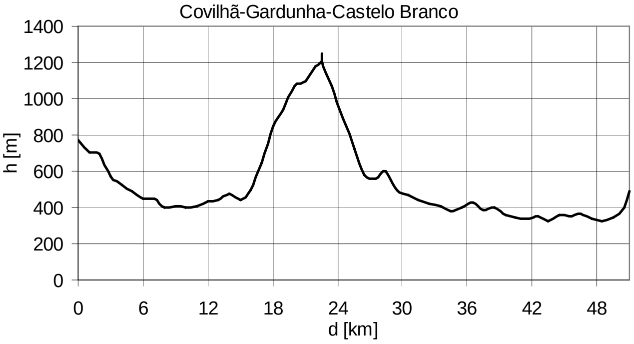


Figure 7: Obstructed path with a relay (in a tower with 40m).

In digital microwave radio links, besides uniform fading (the simple reduction of the signal level, uniform along the band [8]), there is selective fading which, apart from decreasing the power of the received signal and consequently increase the bit error rate (because of the reduction of the carrier-to-noise ratio), may significantly increase bit error ratio due to intersymbol distortion. This effect is due to the fact that the transmission channel is no longer linear. However, in IEEE 802.16 standard the bit error ratio due to selective fading is zero if there is LoS [3, p. 350].

The link margin is defined as the ratio, usually expressed in dB, between the received carrier power, in stable propagation conditions, i.e., without fading, and the carrier power at the receiver input that leads to a given bit error ratio [8]. In general, this bit error ratio is rather high, typically 10^{-3}. Higher bit error ratios lead to frequent link interruptions, due to frame synchronism loss. The link margin corresponds to fading that can be tolerated without significant link interruptions. In most cases, link margin for uniform fading, or uniform margin, is higher than 30-35dB.

When fading is considered, the minimum carrier-to-noise ratio, $C/N_{(min)}$, is given in dB by

$$\left(C/N\right)_{\min\_with\_fading} = \left(C/N\right)_{\min} + m_u , \tag{3}$$

whre m_u is the link margin for uniform fading, in dB.

In the study of fading in LoS paths with no appreciable reflections, the probability P that the received power p is less or equal to p_0, in the worst month, may be estimated by using an expression of the form

$$P(p \le p_0) = k_t \frac{p_0}{p_n} , \tag{4}$$

where p_n is the received power without fading [8].

Introducing the concept of link margin $m = p_n/p_0$, the previous expression becomes

$$P(p \le p_0) = \frac{F}{m} \quad \Leftrightarrow \quad m = \frac{F}{P} , \tag{5}$$

where F is the deep fade occurrence factor, a constant that includes link dependence on the following factors: geoclimatic, terrain, direct ray slope, length and carrier frequency, and follows the Morita's law [8]

$$F = 1.4 \times 10^{-8} \times f_{[GHz]} \times \left[d_{[km]}\right]^{3,5} . \tag{6}$$

In a simple approach, the probability of error occurrence, P, cannot exceed

$$\text{Clause 1 } (ber=10^{-6}) \quad P_1 = \frac{0.004 \times d}{2500},\ \ d \ge 280 , \tag{7}$$

$$\text{Clause 2 } (ber=10^{-3}) \quad P_2 = \frac{0.00054 \times d}{2500},\ \ d \ge 280 , \tag{8}$$

according to ITU-R Recommendations previous the 1997, which were adapted to Wimax. One identifies the power p_0 as the received power that corresponds to the maximum allowed bit error ratio; the probability that the received carrier power is less than p_0 is equivalent to the probability P_c that the maximum bit error ratio is exceeded.

The division of the probability that the bit error ratio is exceeded in two parts (one P_u, due to uniform fading, and the other P_s, due to distortion caused by selective fading) corresponds to an equivalent division of the link margin m

$$\frac{1}{m} = \frac{1}{m_u} + \frac{1}{m_s} , \tag{9}$$

where m_u is the link margin for uniform fading (if there only is uniform fading), or uniform margin, m_s is the link margin for selective fading, or selective fading margin, and $\alpha=2$, where α is one of the parameters defined in the ITU-R Recommendation [4] F.1093-1.

As it has already been mentioned, in LoS conditions, $P_s=0$ in IEEE 802.16; hence, $P_c=P_u$ and $m=m_u$. As a consequence, $C/N_{\min\_with\_fading}$, in dB, can be given by

$$\left(C/N\right)_{\min\_with\_fading} = \left(C/N\right)_{\min} + m + m_{extra} , \tag{10}$$

where m is the link margin, in dB, and m_{extra} is an additional link margin of 3dB. One considers $(C/N)_{min}$=16dB.

By considering γ=2 in Friis equation, a bandwidth of 20MHz, P_t=0dBW, G_t+G_r=2x23.8=47.6dBi, a noise factor of 3dB, 10m of waveguides in antenna feeders in each terminal (with specific attenuation A_t=A_r=0.051dBm), and a specific rain attenuation γ_{rain}=0.015dB/km, one obtained results for the carrier-to-noise ratio, C/N, Fig. 8 (example for clause 2, the worst case). From these figures it is possible to compare the curves of the actual C/N with the curves of $(C/N)_{\text{min}\_with\_fading}$, obtained from (5) and (10), for clauses 1 and 2.

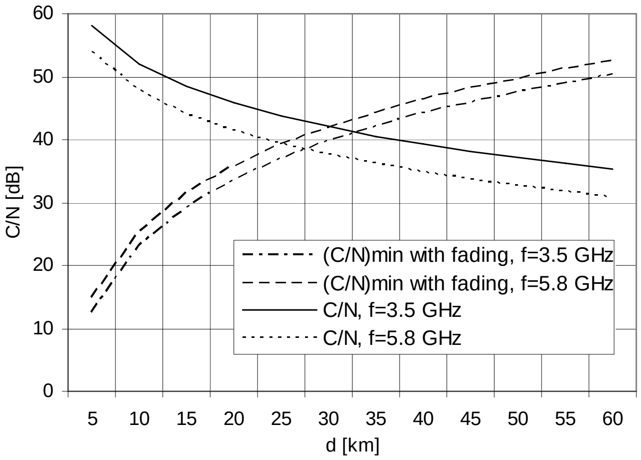


Figure 8: Comparison of the carrier-to-noise ratio with its quality threshold $(C/N)_{\text{min}\_with\_fading}$ for clause 2.

With these antenna gains, while at 3.5GHz it is possible to ensure the radio link Covilhã-Gardunha-Castelo Branco with a relay, at 5.8GHz, as C/N<$(C/N)_{min}$ only up to 25km, an increase of the antenna gain(s) of about 4dB would be necessary. Some care has to be put in the analysis of the sum of the bit error ratios for the two consecutive hops.

5 Conclusions

The number of macro-cell necessary to cover the region of Beira Interior is 35 and 62 cells for coverage distances of 8 and 6km, respectively. While in open space, e.g., rural areas, coverage is not a limitation, in urban areas, high coverage distances will be impossible, and micro-cells with coverage distances up to 3-4km have to be used. The carrier-to-interference ratio analysis, leads to the conclusion that, with omni-directional antennas, minimum reuse patterns of 12 and 4-7 are needed for γ=2 and γ=3, respectively, while, with sectorial antennas, the respective values are 3-4 and 3, increasing system capacity. Hence, sectorisation will be used to reduce the reuse pattern, and cell overlay is suggested to overcome coverage problems in main towns and cities. In large towns and cities a higher propagation exponent has to be considered. As the propagation conditions improve with LoS propagation, GIS tools for LoS discovery have been applied. In the city of Covilhã, after some iterations, one obtains ~75 % of LoS coverage. In these zones a propagation exponent around γ=3 is guaranteed. In the point-to-point link Covilhã-Gardunha-Castelo Branco, it is possible to ensure good quality communications at 3.5GHz by using antennas of 24dBi. However at 5.8GHz, because of the larger distance, good quality is only achieved up to 25km. Hence, it will be necessary to increase the gain of at least one of the antennas.

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References

[1] Harry R. Anderson, *Fixed Broadband Wireless System Design*, John Wiley & Sons, New York, New York, USA, 2003.

[2] Henrique Cunha, Maria Paula Queluz, António Rodrigues, "Microwave Radio Links Spectrum Management Using GIS," in *Proc. of ConfTele' 2005 – 5th Conference on Telecommunications*, Tomar, Portugal, Apr. 2005.

[3] IEEE, *Draft IEEE Standard for Local and Metropolitan Area Networks – Part 16: Air Interface for Fixed Broadband Wireless Access Systems*, IEEE 802.16-REVd/D5, The Institute of Electrical and Electronics Engineers, New York, New York, USA, May 2004.

[4] ITU, ITU-R Recommendations on CD-ROM, ITU, Geneva, 2000.

[5] W. C. Y. Lee, *Mobile Cellular Telecommunications systems*, McGraw-Hill, New York, New York, USA, 1989.

[6] Sanjay Rana, Jeremy Morley, *Optimising Visibility Analyses Using Topographic Features on the Terrain*, Centre for Advanced Spatial Analysis, University College London, London, UK, 2002.

[7] Theodore S. Rappaport, *Wireless Communications – Principles and Practice*, Prentice Hall, Upper Saddle River, New Jersey, USA, 2002.

[8] Carlos Salema, *Microwave Radio Links*, John Wiley & Sons, Hoboken, New Jersey, USA, 2003.

[9] Ricardo Tomé, Pedro Lourenço, António Grilo, Francisco Cercas, Pedro Sebastião, "A Simple Wireless LAN Planning Tool: Technical and Economic Aspects," in *Proc. of ConfTele' 2005 – 5th Conference on Telecommunications*, Tomar, Portugal, Apr. 2005.

[10] F.J. Velez and J. Brázio, "Microcellular Design and System capacity determination for Outdoors Urban Mobile Broadband Communication Systems in the Millimetrewave Bands," in *Proc. of International Conference on Telecommunications*, Chalkidiki, Greece, Jun. 1998.