Aspects of Cellular Planning for Emergency and Safety Services in Mobile WiMax Networks

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***Abstract*— This work addresses cellular planning aspects for a WiMax (Worldwide Interoperability for Microwave Access) point-to-multipoint wireless network to be developed in the region of Beira Interior. It is concentrated in more detail in the district of Covilhã, and, particularly, in the urban area of the city, in order to guarantee communications from the Health Science Faculty of University of Beira Interior (HSF/ UBI)/ Hospital Pêro da Covilhã to all central urban area of the city. By having aspects related with the carrier-to-noise and carrier-to-interference ratios into account, one concluded that it is necessary to consider a cellular structure with sectorisation, and cell coverage distances around 3 km. Because this zone is very hilly, the optimization of the choice of the location for base stations is essential; the potentialities of the GIS (Geographic Information Systems) tools were explored to optimise the existence of line of sight coverage in coverage. Future research directions regarding architectures for interoperability and mobile IP, security, and the impact of multimedia applications are also addressed.**

Index Terms— **IEEE 802.16, cellular planning, GIS, services and applications, interference.**

I. 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 [1], [2] 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. With 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 an 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.

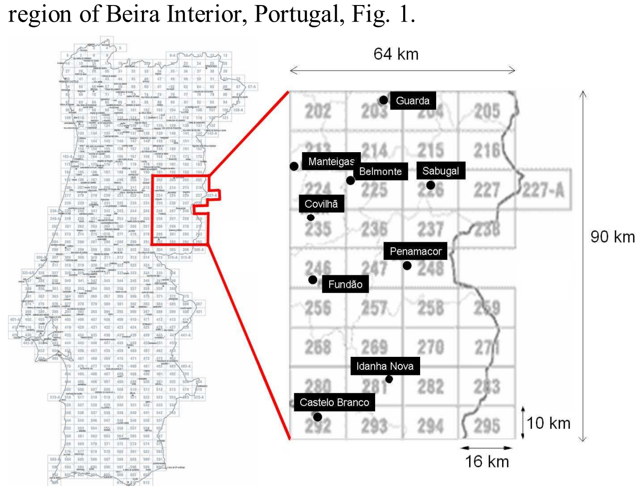


Fig. 1 Beira Interior, Portugal.

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 [3], and a cellular planning tool for IEEE 802.11 indoor Wireless LANs [4]. In these tools, the determination of LoS (Line-of-sight) is based into algorithms for polygon visibility, i.e., visibility chains.

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 [5] but it is not described here.

In Section II one starts by addressing aspects of IEEE 802.16e cellular planning in the region of Beira Interior, Portugal, in terms of both coverage and frequency reuse. As the existence of LoS (Line-of-Sight) is crucial for coverage, Section III presents details on the LoS discovery process in rural and urban areas, describes the backhaul network, and discusses in detail a case study for the city of Covilhã. Besides, frequency reuses issues are also addressed. Section IV presents a brief overview of future research directions on architectures for interoperability and mobile IP, security, and the impact of multimedia applications in the design of WiMax networks. Finally, conclusions are drawn in Section V.

II. MACRO-CELLULAR PLANNING

Over the region of Beira Interior, with an area of 64·90=5760 km^2, the process of cellular planning has to simultaneously account for carrier-to-noise and carrier-to-interference constraints. A simple propagation model [6] is considered where different propagation environments are modelled by different propagation exponents, γ, which vary from γ=2, in free space, e.g., rural areas, to γ=3, in urban areas (no shadowing), and γ=4, in shadowed urban areas [6].

The number of macro-cell necessary to cover the area under study is 35 and 62 cells, approximately, for coverage distances of 8 and 6 km, 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. The analysis of the carrier-to-noise ratio shows the limitations on coverage, Fig. 3. The Friis free space equation is used by replacing the propagation exponent 2 by γ.

By considering G_t+G_r=25 dBi, P_t=0 dBW, a bandwidth of 5 MHz, and a noise factor of 3 dB (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 6-8 dB, it is only possible to achieve $C/N > (C/N)_{min}$ with γ=2 and γ=3, although for γ=3 this is only achievable up to d = 4 km (note that, for higher order modulations, typical values for $(C/N)_{min}$ are of the order of 15-16 dB [1]).

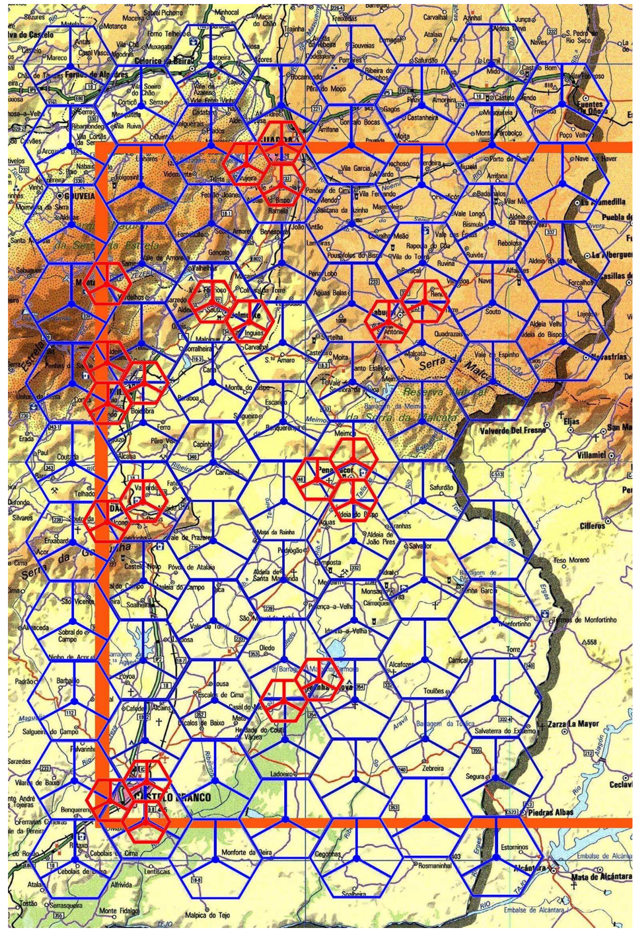


Fig. 2 Cellular layout for the area under study, R = 6 km.

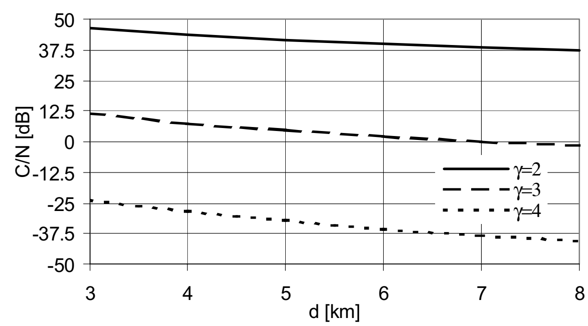


Fig. 3 Carrier-to-noise ratio for different propagation environments and f=3.5 GHz (rain attenuation is included).

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 3-4 km 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 to guarantee a propagation exponent γ~ 3 (maximum).

Regarding co-channel interference [6], with this simple propagation model, the carrier-to-interference ratio is

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

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 [6], for $\gamma=2$, one needs to use a reuse pattern, k, higher or equal to 12 to overcome $(C/I)_{min}$=6-8 dB, Fig. 4. If 120º sectorial antennas are used, the carrier-to-interference ratio is obtained in a different way [7]

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

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 $(C/I)_{min}$ = 15-16 dB.

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, for the design of this network, sectorisation will be used to reduce k 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 have to be included in the tool.

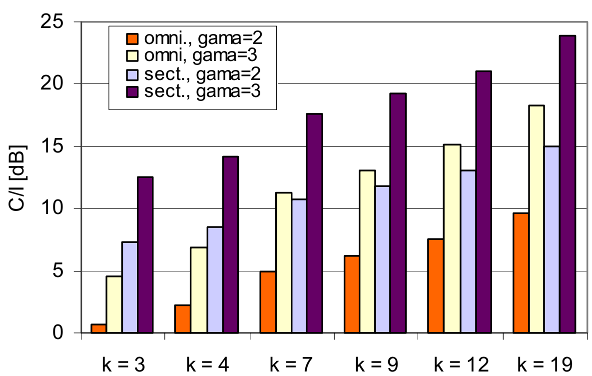


Fig. 4 Carrier-to-interference ratio with omni-directional and sectorial antennas, in different environments.

III. Cellular LoS dimensioning

A. Rural and Urban Areas

LoS discovery should be applied for a better cellular planning, and GIS (Geographic Information Systems) functionalities were incorporated for the choice of the best placement of BSs, including their height. An application is made for the the district of Covilhã, Fig. 5, an area of ~550 km^2. Because this zone is very hilly, cells with coverage distances around 3 km are used, differently from whole region of Beira Interior, where larger cells were considered. By considering 18 sites (marked with circles), and by using digital terrain models and ArcGIS 9.0 [8], 3D Analyst extension, one obtains LoS coverage in ~70 % of the area, Fig. 6.

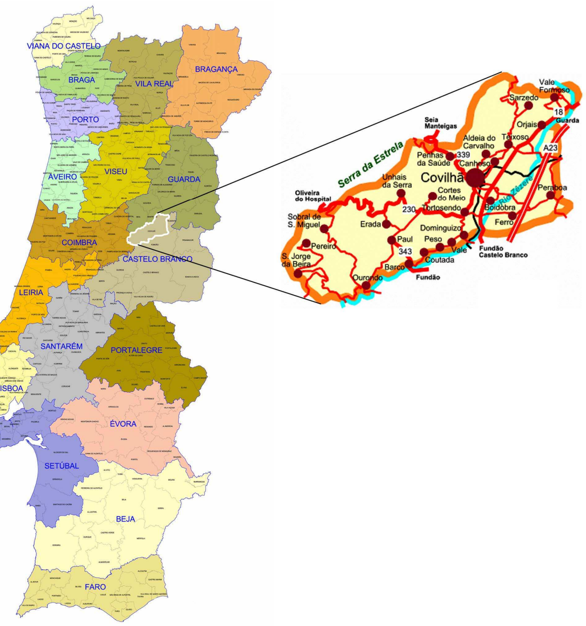


Fig. 5 The district of Covilhã.

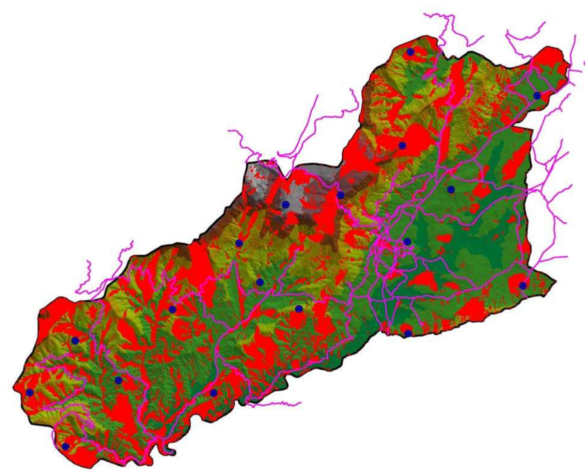


Fig. 6 LoS discovery for the district of Covilhã.

Omnidirectional antennas are mounted on 15 sites (although two of them only cover a 180º sector), while the remaining three sites have two 180º sectorial antennas. There is 83 % of LoS coverage in villages, towns and cities, in average. This guarantees propagation exponents of γ=2 in rural areas and γ=3 in dense urban areas. Furthermore, main roads in the access to the mountain (Serra da Estrela), an important skiing tourist place in centre of Portugal, are covered with LoS. The proposed frequency reuse layout is presented in Fig. 7, where R is the coverage distance and D_1 and D_2 are the distances considered for the computation of interference. By considering terrain relief, this layout guarantees that the maximum carrier-to-interference ratio is almost always above 16-18 dB, the threshold for higher order modulations; however, there is a worst case situation for f_6, for which only lower order modulation can be used because C/I = 7.3 dB.

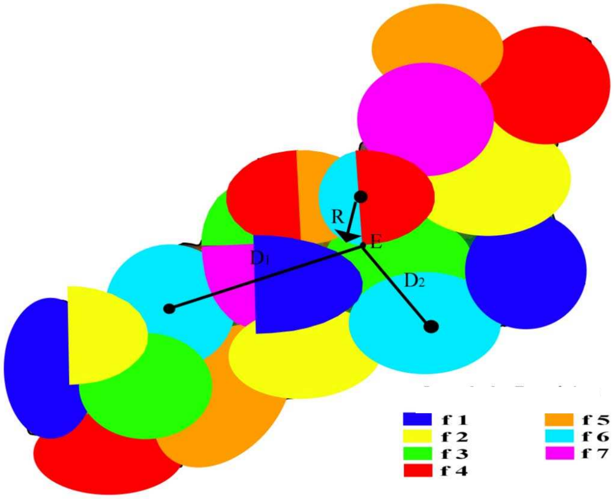


Fig. 7 The district of Covilhã.

B. Backhaul for WiMax Base Stations

By verifying the absence of obstruction of the first Fresnel ellipsoid between base stations, one ensures that there are several possibilities to establish the backhaul for the WiMax network, in alternative to a wired network. If there is optical fibre access in the city of the Covilhã and network access has to be performed through BS8 (Covilhã), in Fig. 8 one presents the choices for the design of wireless links among base stations. Some of these links are established in a star shape format, while the others are sequential.

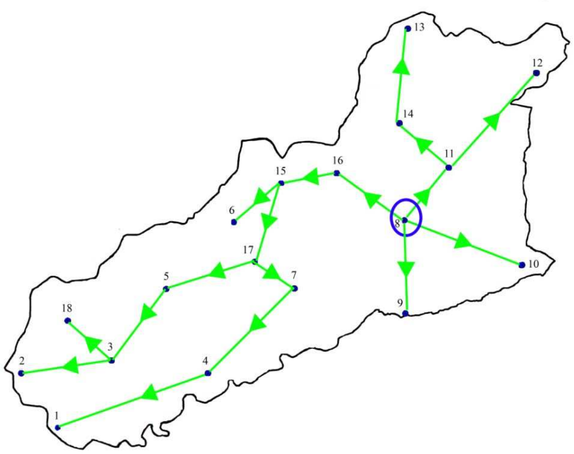


Fig. 8 Proposal of a scheme for the backhaul network.

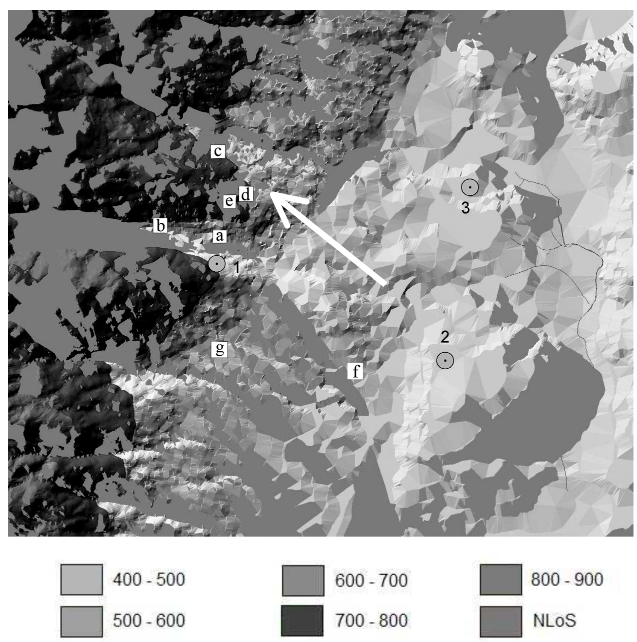
In order to have totally independent base stations the use of solar panels is suggested, to guarantee the necessary power feeding. This scheme presents five point-to-multipoint stars, centred in BS 3, BS 8, BS 11, BS 15 and BS 17, and six point-to-point serial links (BS 14 – BS 13; BS 11 – BS 12, BS 16 – BS 15 ; BS 5 – BS 3; BS 7 – BS 4; BS 4 – BS 1). Omnidirectional antennas are suggested to establish the star links, while directive antennas should be used in serial links.

For the establishment of these links, one assumes the use of the 5.8 GHz frequency band. Besides avoiding interference with the 3.5 GHz equipment, deployed to cover the district of Covilhã, it provides an alternative network, which can be very useful for emergency and safety services, among others. Spatial redundancy has to be explored as future work, and alternative links have to be proposed.

C. City of Covilhã

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 for the coverage of the city of Covilhã have to be carefully chosen through LoS discovery, Fig. 9.

For a given coverage area and cell coverage (radius), a specific exercise is done for the city of Covilhã by using directional antennas, with new locations. By using digital terrain models/features, the process of finding the LoS region "seen" by each BS (BSs 1, 2 and 3 in Fig. 9) is being automated for the city of Covilhã by using ArcGIS 9.0 [8]. Covilhã is a city in the base of the mountain; the white arrow in Fig. 9 represents increasing altitudes, from ~400 m 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).



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

Fig. 9 LoS areas by using digital terrain information.

In the area under study, and after some iterations, if the zones with no pedestrian or car access are discounted, one obtains a LoS coverage area of ~75% (where the NLoS areas are represented by grey spots, Fig. 9). In these zones a propagation exponent around $\gamma = 3$ is guaranteed.

IV. Future Work

The MobileMAN (Mobile IP for Broadband Wireless Metropolitan Area Networks) project intends to design or plan fixed/portable and mobile WiMax WMANs (Wireless Metropolitan Area Networks), pioneering implemented in Portugal. Besides the benefits of its operation in the context of university, hospital and urban environments it will be very useful for demonstration and research purposes. The project involves five main tasks: i) the design and development of IEEE 802.16 microwave links for fixed/portable communications, ii) planning of a cellular IEEE802.16e network for mobility support, iii) network architectures for interoperability and mobile IP (e.g., between WiFi and WiMax networks), iv) security for IEEE 802.16, and v) multimedia services and applications for mobile platforms. While task i) is not being covered in this paper, and details on task ii) have already been covered throughout the text, tasks iii)-v) will be briefly presented in what follows.

Mobile IP and micro-mobility are new challenging areas of research. Besides innovative contributions to research on Mobile IP, one will conceive, develop and implement the new mobile IP architecture, with new bridges/routers and servers. Gradually, one will implement several levels of mobility support, by means of appropriate architectures, and the migration to IPv6.

In the design and implementation processes, it is fundamental to identify vulnerabilities, to evaluate and test global security harmonization and systems integration for the network infrastructure equipment and solutions. Based on this evaluation, security mechanisms will be implemented for the overall network, including the WiMax component, WiFi islands, and fixed network.

The task on multimedia services and applications for mobile platforms encompasses detailed understanding of the unique technical and performance requirements of network multimedia communications, analysis of the performance of multimedia service in IEEE 802.16 networks, developments of a capacity planning model, and adaptation and deployment of existing services (and their customisation for use, e.g., to cope with IPv6 and the need for mobility support).

V. Conclusions

The number of macro-cell necessary to cover the region of Beira Interior with an IEEE 802.16e network is 35 and 62 cells for coverage distances of 8 and 6 km, 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 3-4 km 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 $\gamma=2$ and $\gamma=3$, respectively, while, with sectorial antennas, the respective values are 3-4 and 3. Hence, 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, in average. Furthermore, in these places, sectorisation will increase system capacity.

In hilly regions, good coverage conditions are essential. As the propagation conditions improve with LoS propagation, GIS tools for LoS discovery have been applied. In the district of Covilhã, by using 18 antenna sites, 70% of coverage is guaranteed for the whole zone. Besides, there is 83 % of LoS coverage in villages, towns and cities. Wireless point-to-multipoint links have been suggested to establish the backhaul of the WiMax network. In order to improve system capacity one considered 120º sectorial antennas in the city of Covilhã, a city placed in the base of the mountain, in a different exercise. After some iterations, one obtains ~75 % of LoS coverage. In these zones a propagation exponent around $\gamma = 3$ is guaranteed.

As this is a challenging field of research, future work directions have been described, including network architectures for interoperability and mobile IP, security for IEEE 802.16, and multimedia services and applications issues.

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