Cellular Planning of an IEEE 802.16 Wireless Metropolitan Area Network

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***Abstract* — This work intends to develop a WiMax (*Worldwid Interoperability for Microwave Access*) point-to-multipoir wireless network that includes all the district of Covilhã, an particularly the urban area of the city in detail, with the objectiv to guarantee a point-to-multipoint connection from the Healt Science Faculty of the University of Beira Interior (HSF/UBI) Hospital Pêro da Covilhã to all urban area of the centre of th city. The cellular planning of this WiMax mobile network was done having in account aspects related with the carrier-to-noise ratio and carrier-to-interference ratio, concluding that is necessary to consider a cellular structure with coverage distances of 3 km and sectorisation is needed to create a high capacity wireless network in the urban area of Covilhã. Because this zone is very hilly, the choice of the location for base stations is essential; one used the potentialities of the GIS (*Geographic Information Systems*) tools to optimize the line of sight coverage and, simultaneously, reduce the propagation exponent. A new mobile IP architecture for Wi-Fi/WiMax interoperability is being conceived, developed and implemented based in Media Independent Handover.**

***Keywords* — Cellular planning, GIS, IEEE 802.16, interference, services and applications**

I. Introduction

RECENT evolution of mobile and wireless multimedia (MM) communications is stimulating the production of new services and applications to be supported in handheld terminals, like mobile phones, PDAs and Tablet PCs, and is motivating the need for increasing mobility in the context of seamless communications, with continuity from indoors, e.g., WLANs, to outdoors environments (e.g., 2.5G or 3G mobile support). After UMTS introduction, the main market players are realising that higher capacity high data rate seamless communications, supporting high mobility, need a lot of research effort, for developing concepts for systems beyond 3G (e.g., Enhanced UMTS, WLANs, WMANs, and reconfigurability). People want the kind of coverage and flexibility (e.g., international roaming) that they find in 2G systems but they want much more: to be always best connected (ABC), with exchange of truly wide and broadband multimedia content, simultaneously supporting voice, data, streaming, image and video multi-rate communications, and new network modes as well, e.g., multicast and peer-to-peer.

Worldwide, the trend is All-IP based communications. Several access technologies are thus in order, and there is room for new ways of giving access to MM users anywhere, anytime, and anyway, in an efficient manner. One strong candidate is the new IEEE 802.16 standard for public (and even private/ unlicensed) networks. It provides wireless broadband access in metropolitan areas, with point-to-point and point-to-multipoint (mobile) configurations, and will revolutionize worldwide broadband access. This standard significantly simplifies the entry of independent operators seeking to become providers of broadband services, and will almost certainly bring about declining equipment prices, and improved network reliability and service levels. Besides, it is also attractive for private players (e.g., communication within University Campus, large Industry plants, and metropolitan distributed organisations).

IEEE 802.16 WiMax (Worldwide Interoperability for Microwave Access) gains special interest for public emergency and safety services, e.g., fireman, police, ambulances. In the context of Universities and Hospitals other applications are e-learning and e-health, while users are moving or at home, and need to communicate; hence, our work addresses a cellular structure that covers the entire district of Covilhã, Portugal, Fig. 1. While the overall cellular structure is mainly dedicated to emergency and security public services, urban micro-cells will specifically support e-learning and e-health services, among others. For demonstration purposes, a network will initially be deployed in the city of Covilhã by using IEEE 802.16d [1]. It will support fixed/portable connections, at typical speeds starting in 70 Mbps down to 6 Mbps, over a range of 50 km maximum.

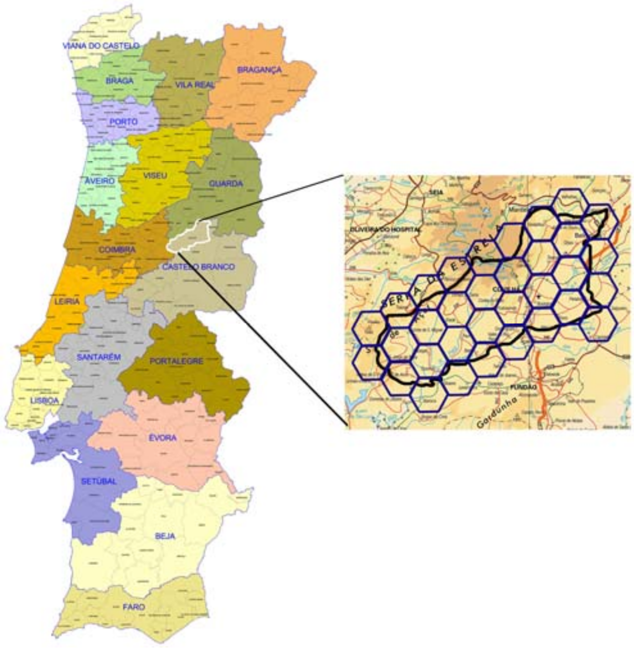

Fig. 1. Cellular layout of the district of Covilhã, R = 3 km.

Later, by using the IEEE 802.16e standard [2], one will support true mobility. This network will be the basis for research and demonstration of broadband mobile access, mobile IP, and always best connected scenarios. Extensive field tests and measurements will be performed. The planning of the wireless network will take into consideration aspects as coverage, different traffic densities, interference and cost minimisation. Because this is a difficult task to be done on a case by case basis, it is important to use cellular planning tools. This work intends to develop the concept and tools to automate the WiMax planning process by 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 [3].

Network architectures for interoperability and mobile IP among Wi-Fi, WiMax, UMTS (including All-IP HSDPA/ HSUPA – High Speed Downlink/Uplink Packet Access) networks are also being envisaged. One is conceiving, developing a new mobile IP architecture for interoperability.

Section II presents aspects of cellular planning, and discusses the variation of carrier-to-noise ratio and carrier-to-interference ratio with different parameters; the use of sectorisation in order to create a high capacity network in the urban area of Covilhã is also discussed. In Section III the potentialities of Geographic Information Systems are explored for LoS discovery in the district of Covilhã. In Section IV Network Architectures for Interoperability and Mobile IP among Wi-Fi, WiMax, and UMTS networks are being envisaged. Finally, conclusions are presented in Section V.

II. Cellular Planning

Over the district of Covilhã, with an area of 550 km^2, the process of cellular planning has to simultaneously account for carrier-to-noise and carrier-to-interference constraints. A simple propagation model [4] 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 [4].

The number of cells necessary to cover the area under study is 24 and 14 cells, approximately, for coverage distances of 3 and 4 km, respectively. They are obtained by dividing the total area by the area of each hexagonal cell.

The cellular planning tool [5] is being expanded to include WiMax design functionalities. It will enable to achieve results as in Fig. 1. The analysis of the carrier-to-noise ratio shows the limitations on coverage, Fig. 2. The Friis free space equation is used by replacing the propagation exponent 2 by γ. One considers 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).

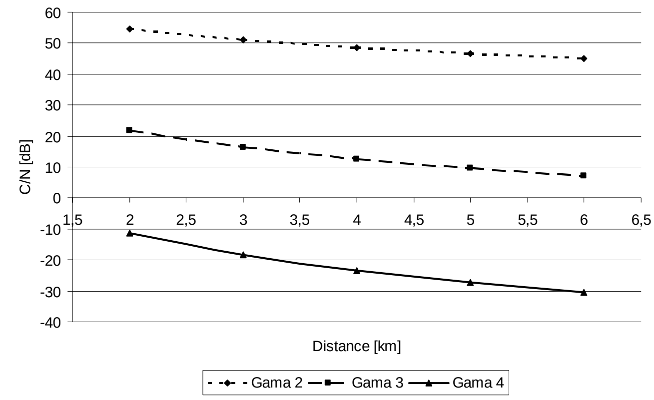

Fig. 2. Carrier-to-noise ratio for different propagation environments and f=3.5 GHz (rain attenuation is included).

Fig. 2 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 = 6 km (note that, for higher order modulations, typical values for $(C/N)_{\min}$ are of the order of 15-16 dB [1]). Hence, while in open space, e.g., rural areas, coverage is not a limitation, in urban areas, high coverage distances will be impossible, and cells with coverage distances, R, up to 3-4 km have to be used. 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 γ=3 (maximum).

Regarding co-channel interference [6], 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 [6], for γ=2, one needs to use a reuse pattern, k, higher or equal to 9 to overcome $(C/I)_{min}$=6-8 dB,

Fig. 3. If 180º sectorial antennas are used, the carrier-to-interference ratio is obtained in a different way [6]

$$C/I = \frac{R^{-4}}{(D+0.7)^{-4} + D^{-4}} = \frac{1}{(q+0.7)^{-4} + q^{-4}} . \qquad (2)$$

Better results are achieved, Fig. 3, and k=3-4 is sufficient. 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. Sectorisation will be used to create a high capacity network in the urban area of Covilhã, and the use of ominidirectional antennas is proposed (in most of the cases), with coverage distance arround 3 km, for the coverage of the district of Covilhã. Besides, functionalities of optimisation/choice of high altitude position for BSs (base stations) have to be included in the tool.

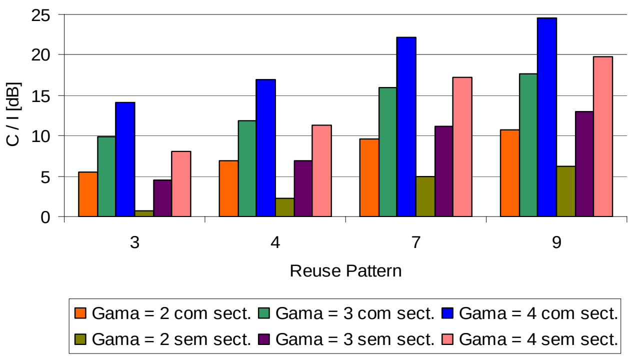

Fig. 3. Carrier-to-interference ratio with omni-directional and sectorial antennas, in different environments.

III. Cellular LoS dimensioning

LoS discovery should be applied for a better cellular planning, and the tool incorporates GIS (Geographic Information Systems) functionalities for the choice of the best placement of transmitters, including their height. An application is made for the region of the district of Covilhã, Figs. 1 and 4.

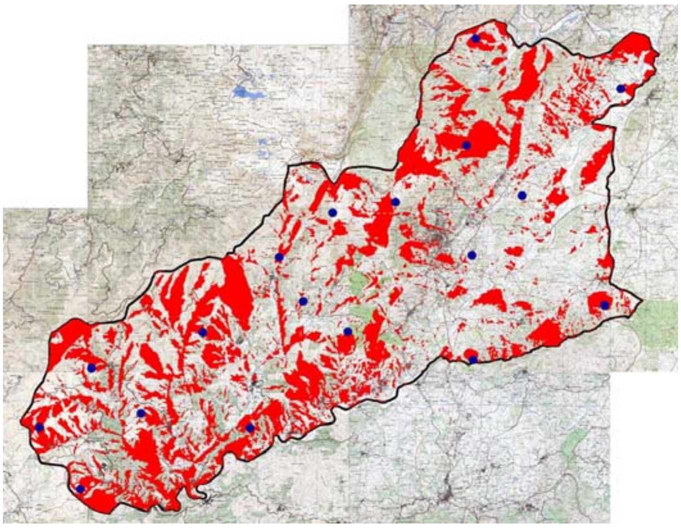

Fig. 4. LoS discovery for the district of Covilhã.

Because this zone is very hilly, cells with coverage distances around 3 km are used. By considering 18 sites (marked with circles), one obtains ~70 % of LoS coverage, Fig. 4, by using digital terrain models and ArcGIS 9.0 [7] (3D Analyst extension). Omnidirectional antennas are mounted on 15 sites (although two of them only covers a 180º sector), while the remaining three sites have two 180º sectorial antennas. There is 83 % of LoS coverage in villages, towns and cities. 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 frequency reuse layout was also obtained, and a scheme for the wireless backhaul network was proposed.

IV. Network Architectures for Interoperability and Services Integration

In MobileMAN (Mobile IP for Broadband Wireless Metropolitan Area Networks), an internal project from *Instituto de Telecomunicações* [8], gradually, one will implement several levels of mobility support, by means of appropriate architectures. In mobile networking, computing and communication activities should not be disrupted when the user changes the computer's point of attachment to the networks. Instead, all the needed reconnection occurs automatically and non-interactively.

However, there are still some technical obstacles that must be overcome before mobile networking/interoperability can become effective, namely difficulties on creating or obtaining a topologically correct address for the correct point of attachment. One possibility will be IEEE 802.21. The standards address two kinds of handover. On the one hand, homogeneous handovers across similar points of attachment such as Wi-Fi APs and WiMax base stations within a single network are handled by the respective access networks' technology standards. On the other, heterogeneous handovers are defined as handovers across different networks and are applicable to multi-radio client platforms. The emerging IEEE 802.21 standard enables handover and interoperability across heterogeneous network types including both 802 and non-802 networks. The IEEE 802.21 Media Independent Handover (MIH) standard [9] provides link layer intelligence and other related network information to upper layers to optimize handovers between heterogeneous media. The standard can support handovers for both mobile and stationary users. For mobile users, handovers may occur due to a change in wireless link conditions or a gap in the radio coverage, resulting from movement of the client.

The IEEE 802.21 standard supports cooperative use of mobile clients in addition to the network infrastructure. The mobile client is capable of detecting available networks, and the infrastructure can store required network information, such as neighbourhood cell lists and the location of mobile devices. In general, both the client device and the network's points of attachment (WiMax base stations or Wi-Fi APs) can support multiple radio standards (multimode) and, in some cases, they may use more than one interface simultaneously.

The standard provides architecture to support transparent service continuity while a mobile node switches between heterogeneous link layer technologies. This architecture relies on the identification of a mobility-management protocol stack within the network elements. As shown in Fig. 5, handover-enabling functions within the mobility management protocol stack include the MIH function. The standard also defines various Service Access Points and associated primitives that provide access to the MIH function services. Upper layers of MIH make handover decisions and link selections, based on inputs and context from the MIH function.

Recognizing that a handover should take place and discovery of information on how to make effective handover decisions are the key components of the IEEE 802.21 standard. MIH function helps to maintain user connections, enables optimum network discovery and selection, and can power radios on or off based on network availability, to extend batteries life.

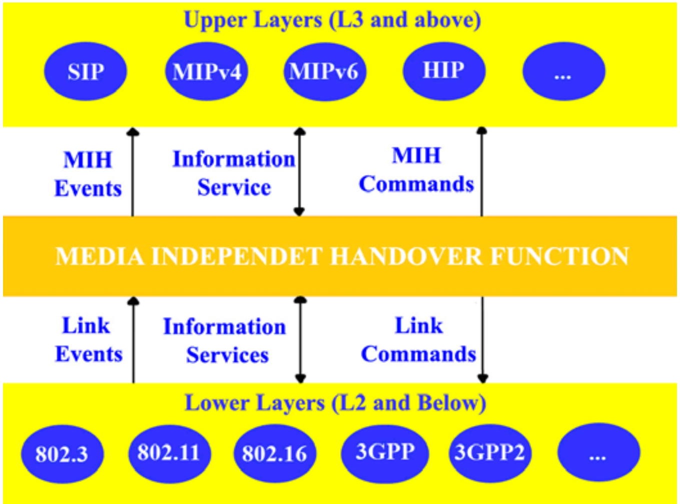

Fig.5. Inclusion of the Media Independent Handover (MIH) function.

V. CONCLUSIONS

The number of cell necessary to cover the district of Covilhã is 24 and 14 cells for coverage distances of 3 and 4 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 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 9 and 4-7 are needed for γ=2 and γ=3, respectively, while, with sectorial antennas, the respective values are 3-4 and 3. Hence, sectorisation will be used to create a high capacity network in the urban area of Covilhã, antennas with coverage distance around 3 km are suggested because of the irregular terrain relief.

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, in practice, 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 which guarantee a propagation exponent, γ=2. In the context of this network, one is conceiving, developing and implementing a new mobile IP architecture for interoperability based in MIH.

ACKNOWLEDGEMENTS

This work was partially funded by MobileMAN (an internal project from Instituto de Telecomunicações), by CROSSNET (a Portuguese Foundation for Science and Technology POSC project with FEDER funding), and by "Projecto de Re-equipamento Científico" REEQ/1201/EEI/ 2005 (a Portuguese Foundation for Science and Technology project). The authors acknowledge the fruitful contributions on ArcGIS tools from Engº José Romão of STIG-UBI (*Serviço Transfronteiriço de Informação Geográfica da UBI*).

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