

Chapter 10

Business Models and Cost/Revenue Optimization

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Abstract This Chapter starts by covering general aspects about the business models for WiMAX and then addresses the cost/revenue optimization for these networks, for cellular configurations without and with relays. In Fixed WiMAX, radio and network planning can be optimised by tuning a cost/revenue function which incorporates de the cost of building and maintaining the infrastructure and the effect of the available resources on revenues. From the cost-benefit analysis, one conclusion of this work is that given today's hypothesis of price per MByte of information transfer of somewhere between 0.0025 € and 0.010 €, it is clear that, without considering the use of relays, the choice of reuse patterns 3 or 4 with sectorial cells is preferable to the use of omnidirectional cells with reuse pattern, K , of 7, as three times more resources are available in each cell. Besides, in nowadays networks, if there is a need for sparse BS deployments whilst reducing costs, $K = 1$ may be a solution, as it presents higher profit for the longest coverage distances. In future networks, when costs will be lower, the advantage of sectorization is kept and will drive the deployment of tri-sectorization forward. Nevertheless, in this case $K = 1$ will not be advantageous with tri-sectorization for the longest coverage distances anymore. This study also concludes that cell radii in the range 1000–1500 m is preferable, corresponding to profit in percentage terms of near the achievable maximum, while keeping costs acceptable. The WiMAX cost-benefit optimization is also explored for the case where relays are used to help on improving coverage while mitigating the interference. Results show that the use of relays with no sectorization in the BS leads to a lower profit ($K = 3$). Also the use of sectorization (an example is presented for $K = 1$) does not seem to enable larger profit. The optimum (maximum) values occur for coverage distances up to 1,000 m. In the DL, when the price per MB, R_{144} , increases from 0.0025 €/min to 0.005 €/min the profit increases more than 100%.

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10.1 Introduction

Although the oldest wireless Internet providers have been providing narrowband since perhaps 1992, the broadband wireless access (BWA) business is a relatively new phenomenon. Some early wireless broadband technologies like LMDS and MMDS tried to establish their roots and to become popular. These were fragmented and competing proprietary standards and did not prove to be 100% successful. They also lacked the broad industrial support like WiMAX is having through the WiMAX Forum. Along with WiMAX, the other nowadays technologies providing wireless broadband are HSDPA, HSUPA, and EV-DO etc.

WiMAX deployment optimisation can be achieved by appropriately parameterising a merit function, taking costs and revenues into account. The optimisation of the cost/revenue trade-off provides a means of combining several contributing factors in cellular planning: determination of the reuse pattern, coverage distance, and the resulting supported physical throughput.

Given the current state of national frequency spectrum assignments throughout Europe, the Fixed WiMAX achievable frequency reuse pattern, K , determines the reduction in the initial fixed cost if the required spectrum bandwidth is reduced to values comparable to the ones for Wideband Code Division Multiple Access (WCDMA) systems. In turn, the supported throughput will determine the achievable revenue, which has interdependencies with the use (or not) of sub-channelisation and/or sectorization. The optimization of the cost/revenue trade-off for different topologies is thus of fundamental importance, and can be achieved by varying system parameters and implied coverage and reuse distances.

A cost/revenue function has to be developed by taking into account the cost of building and maintaining the infrastructure, and the way the number of channels available in each cell affects operators' and service providers' revenues. Fixed costs for licensing and spectrum bandwidth auctions (often known as "beauty contests") should also be taken into account. The economic analysis is referred as a cost/revenue performance analysis, because the optimisation (i.e., minimization) of cost does not necessarily mean the optimization of net revenues. Although one considers a project duration of 5 years as a working hypothesis in radio and network planning, it is decided in this paper to analyse costs and revenues on an annual basis. Furthermore, our analysis is under the assumption of a null discount rate. By no means is it intended to perform a complete economic study in this paper, the aim is simply to present initial contributions that facilitate cellular planning optimisation. Appropriate refinements would be needed to perform a complete economic analysis based on discounted cash flows (e.g., to compute the net present value).

Besides addressing business models and plans in Sections 10.2 through 10.4 the main contributions from this chapter are the following. Section 10.5 describes the range of services offered. Section 10.6 addresses cost/revenue optimization, presenting the models without and with considering relays, as well cost/revenue optimization results and profit.

10.2 Business Model Definition

The term “business model” describes the interrelationship between different entities of the value network. A technology can be made successful only if it is supported by a successful business case.

A complete business model comprises inputs from two domains, technical and economic. As shown in Fig. 10.1, a business model forms the link between creative technological ideas and the economic implementation of an innovation.

A business model draws on a multitude of business subjects, including economics, entrepreneurship, finance, marketing, operations, and strategy. The business model itself is an important determinant of the profits to be made from an innovation. Sometimes it is seen that a mediocre innovation with a great business case may be more profitable than a great innovation with a mediocre business case.

The basic business model is used to analyse the various service, organisational, technology and financial aspects. A right business model describes the interrelationships between different entities of the whole value network and the processes that take place between each of them.

10.3 Broadband Communications Business

There are many market drivers which has made broadband communications so popular. Some of them are new technologies, new applications, increased computing power and storage, mass production, price reductions, the Internet revolution and the competition. Also new technologies, the mass production of network components and low transmission costs are continuously creating new applications. At the same time, an extraordinary expansion of the Internet has occurred. It seems that it is not a killer application for the broadband market, but that Internet is a ‘killer network’, with a “killer” cocktail of applications and services.

WiMAX is a highly versatile BWA technology platform and has relevance to a wide variety of application scenarios. The promise of WiMAX lays in its open

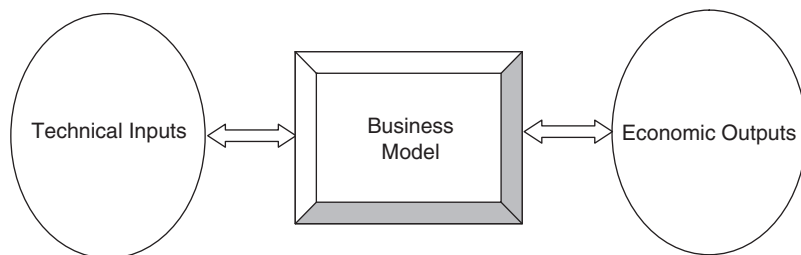


Fig. 10.1 Generic business model

standard design and capacity for interoperability. As a standard-based technology, with a huge ecosystem of developers and industry players, WiMAX is a technology of choice for the wireless broadband future. WiMAX wireless broadband is expected to evolve at a rapid pace, connecting the unconnected and bringing new possibilities to consumers and enterprises.

With an OFDMA air interface, all IP architecture, adaptive modulation and coding techniques, and multiple advanced antenna options (including MIMO and beamforming), WiMAX promises high performance connections to deliver fixed broadband with deep penetration as well as high throughput. IEEE 802.16e, IEEE 802.16d and then IEEE 802.16m are expected to address a new breed of devices, applications and services that rely on broadband connections for enhanced user experience.

Currently, there are very few commercial WiMAX compliant networks deployed. At the end of 2007 there were a total 181 operators globally. This number is expected to rise to 538 by 2012 [1]. New players are coming up in the WiMAX business. These are from diverse industries such as broadcasting, content studios, utilities and consumer electronics focused on providing fixed and mobile broadband mix services as an alternative to wireline technologies.

The business model for the WiMAX deployment must consider all the aspects of design, deployment, and integration from the core network through the systems architecture, service edge, access network and devices.

10.4 Developing a WiMAX Business Plan

10.4.1 Market Research: Gathering the Input Parameters for a WiMAX Business Case

In order to make a successful business case extensive market research has to be done. The inputs gathered from the research vary from country to country, but will help to deploy a feasible network deployment depending on the financial, technical and business parameters.

10.4.1.1 Target Market Characteristics

The first step in the market research is to decide the geographic area to be covered under the WiMAX services. This is measured in square kilometres of coverage for urban, suburban and rural geographies. The accurate network planning is possible when the terrain type of the geographical area is known. The terrain type can be classified under flat, moderate hilly or hilly. Geographic Information System (GIS) tools are used to explore aspects in network planning.

10.4.1.2 Spectrum

Licensed radio spectrum is the prime asset of a WiMAX network, and its value is determined by many factors, including its frequency, capacity and whether it is fixed or mobile. Recognizing the virtues of WiMAX for broadband wireless access the global regulators have allocated new spectrum channels. Globally the spectrum allocated for WiMAX is around 2.5 and 3.5 GHz bands. Around 500 companies worldwide have BWA licenses in the 3,400–3,600 GHz frequency bands while a few have licenses in the 2,500–2,690 GHz band .The typical deployment characteristics of the BWA bands are listed in Table 10.1.

10.4.1.3 Technological Parameters

Once the target market characteristics are found out and the bandwidth is known the technological parameters need to be decided. Nowadays, the first technological selection is between 802.16d or 802.16e. To achieve ubiquitous coverage throughout the entire geographical area, technical parameters such as link budget, spectral efficiency and antenna configuration need to be decided. These parameters along with the frequency to be used will help to calculate the coverage area (with no considerable interference) per cell site, hence, the total number of base stations to cover the desired geography.

The radio characteristics of the WiMAX equipment selected for the analysis in this Section are listed in Table 10.2.

Table 10.1 Characteristics of 3.5 and 2.5 GHz frequency bands

Features	3.5GHz	2.5GHz
Total available spectrum	About 200 MHz between 3.4 GHz and 3.8 GHz (varies from country to country)	195 MHz, including guard –bands and the MDS channels ,between 2.495 and 2.690 GHz
Serviced offered FDD or TDD	Fixed, may allow mobile Mixed, some countries specify FDD only while others allow either FDD or TDD	Fixed and Mobile TDD/FDD
Spectrum per license	Varies from 2*5 MHz to 2*56 MHz	22.5 MHz per license, a 16.6 MHz block paired with a 6 MHz block. Total eight licenses
License aggregation Allocation	No Worldwide except in US	Yes U.S., Canada, Latin America, Australia, expected in Asia

Table 10.2 Radio characteristics

Attribute	3.5 GHz	2.5 GHz
Duplexing	FDD	TDD
Channel bandwidth	2×3.5 MHz	5 MHz
Adaptive modulation	BPSK, QPSK, 16QAM, 64QAM	
System gain	158 dB	157 dB
Path loss for indoor CPEs	15 dB	
Propagation conditions	Urban, suburban and rural under NLoS conditions	

10.4.1.4 Determining Financial and Capital Expenditure (CapEx)

There are certain financial parameters which need to be assumed or taken into account before the operator starts the actual network planning. Critical evaluation regarding interest rates on borrowing and the expected returns need to be forecasted. The tax rate on profits, depreciation and the amortization period should also be taken into account.

As in any major network deployment, huge initial capital is required to procure the WiMAX equipment as well as to acquire or lease sites. The setup of the access network also adds to the capital expenses (CapEx). This includes not only the base station costs but also the other components in the access network.

10.4.2 Market Planning

10.4.2.1 Competitive Analysis

There are a host of broadband service providers in the market today. The operator must take into account the penetration, type of services and their pricing levels by the existing broadband players. These include DSL and cable providers, on the wire-line side, and the 3G service providers, on the wireless side. A complete and understanding of the competitive environment for the broadband services in the operators market is necessary to develop a viable business plan.

10.4.2.2 Coverage Requirements

The main goal of the WiMAX operator is always to achieve the ubiquitous coverage throughout the entire metropolitan target area. An operator can develop a plan for rolling out the network based on different scenarios, for example, to consider the number of customers.

10.4.2.3 Capacity Requirements

Traditionally cellular networks were deployed to achieve ubiquitous coverage, with very little consideration for capacity requirements. This was the most reasonable approach as the only service offered was voice. More base stations were installed when the customer base and the number of services offered grew. However, with broadband, a range of services with varying Quality of Service (QoS) and Quality of Experience (QoE) are offered. To meet the customer expectations for these type of services it is of prime importance to predetermine the capacity requirements and accordingly deploy at the outset. This will ensure a quality user experience (even in the busiest ours in the highest density urban areas).

Data density, expressed in Mbps per km², is used to describe capacity requirements. Determining the data density requirements for a specific demographic region is multi-step process shown in Fig. 10.2.

The service provider generally offer plans with varied service level agreements (SLAs) to appeal wide range of anticipated customer types in the target market segment. An SLA is a negotiated agreement between a service provider and a consumer for a subscription choice which typically defines the service level offered for a given monthly fee. There will be different sets of SLAs for residential and business segments.

Depending upon the capacity to be offered the operator also need to decide on the oversubscription rate. Oversubscription means assigning a total committed information rate to a given base station that is greater than the base station capacity. This number is used to determine the peak busy hour traffic. As the number of users increases, a calculation using the oversubscription rate will tell the operator when to add new cells for the increased usage.

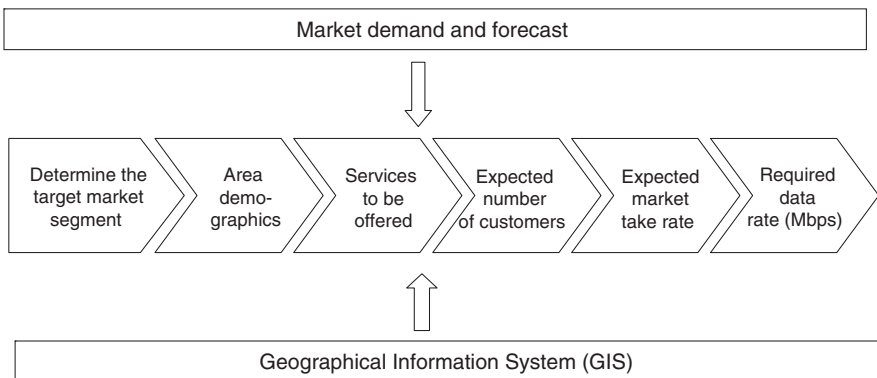


Fig. 10.2 Determining market driven capacity requirements

10.4.2.4 Penetration

When building a broadband wireless access network, it is difficult (as well as challenging) to forecast number of subscribers that an operator can expect to sign over the life of the network. It generally takes a period of time for consumers to buy a new technology, a new service or opt for a new provider of that service. For some consumers the technology, service and provider have to be well-tested before they will sign up for the service. But the success of Wi-Fi will help WiMAX for a general acceptance of broadband wireless access. The rates charged for services by the operator will also have a marked effect on how quickly the technology and services will be adopted. Operators will also have a quicker adoption rate in past non-covered area than in areas that are currently well served.

In Fig. 10.3, curves for the number of subscribers over a 10 year time frame are plotted. It shows that for first couple of years there are very few subscribers [2]. As the operator is deploying the network and expanding coverage the number of subscribers increases. Once the network is fully deployed, there will be an increase in subscribers until some level of saturation is reached.

10.4.2.5 CapEx

In analysing the business case, capital expenditure (CapEx) is calculated by taking into account the end to end network, as described in Fig. 10.4. The major CapEx components are the following:

- Spectrum licenses
- Customer Premise Equipment (CPE)
- Base station infrastructure

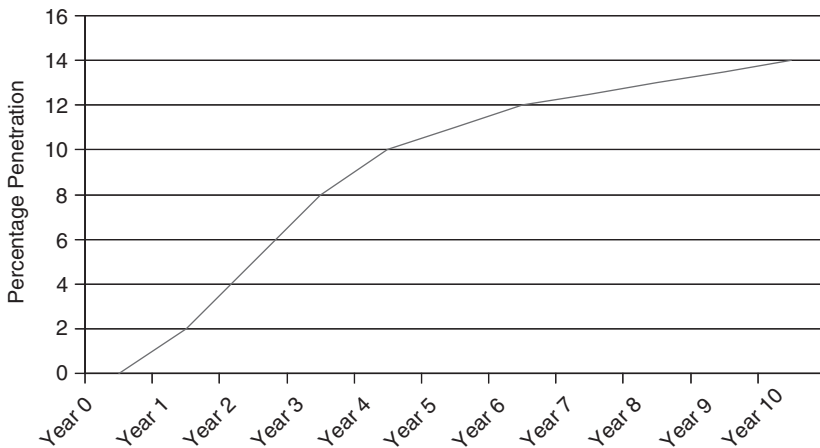


Fig. 10.3 WiMAX penetration curve

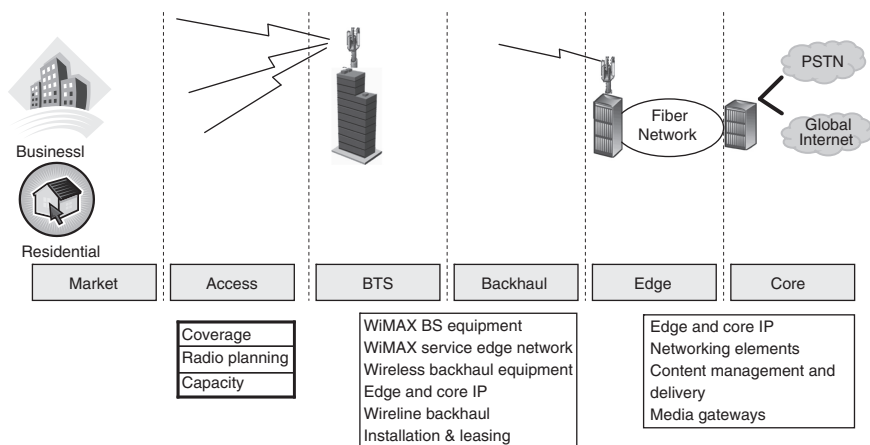


Fig. 10.4 WiMAX end-to-end network

- Edge, core and central office
- Wireless backhaul equipment
- Site development and acquisition cost

The CapEx is different for the incumbent compared to a new operator. For an incumbent wire-line operator, at least some part of the edge, core and central office equipment is ready. The only need is to add capacity to support the additional anticipated customers that would be covered by the WiMAX portion of the access network. Nevertheless, for the new operator large investment is required for edge, core and central office.

As shown Fig. 10.4 the wireless portion the network begins at the fiber node or microwave link with a WiMAX BS or a wireless point-to-point link to a remotely located WiMAX BS. This backhaul link can be a WiMAX compliant point-to-point solution or some other point-to-point radio technology evolution.

In addition to the WIMAX equipment, the base station may also include additional hardware such as the uninterruptible power supplies, electronic cabinets and some other additional equipment for the interface with the backhaul link.

The costs for the civil works including antenna masts, conduits, cables, and the overall base station preparation also need to be considered.

The base station infrastructure CapEx items are fixed in costs and are labour intensive. The cost is different for developing countries compared to developed ones. The civil works for urban area deployments are also higher compared to suburban and rural areas.

10.4.2.6 OpEx

As in any major network deployment, the total cost of ownership of a WiMAX network will comprise of operating expenses along with the capital expenditures.

Table 10.3 Operating expenses

Operating expenses (OpEx)
Site rental
Site utilities
Backhaul installation
Backhaul cost
Network maintenance
Support and warranty
Billing/CRM
Marketing and advertisement
Equipment maintenance
Bad debt and churn
General and administrative expenses

The operating cost comprises of the ongoing operational expense of managing and maintaining the WiMAX service.

The major operational expenses are given in the Table 10.3. While considering the WiMAX business case its important for the operator to consider the various type of subscriber's stations or terminals used with various SLAs. CPEs can be fixed (indoor and outdoor), WiMAX cards integrated in laptops, portable CPEs or embedded in consumer electronics (CE) devices. The business case should include the price of the CPE, it can be either subsidised by the operator or paid by the consumer.

10.5 Range of Services Offered

Today the broadband service no longer means just high speed Internet access. Broadband has successfully evolved to become the enabler of a bouquet of IP services. It's no longer enough to provide the high speed internet facilitates such as surfing, e-mailing, file sharing, instant messaging, operators need to launch additional applications, too

Therefore, an extensive review of service provider strategies must be made. WiMAX has to be more about services than it is about technology. The more services an operator is able to successfully leverage on its network, the more valuable the network becomes.

The first step in defining the market is the range of services that would be offered to the potential customer. The right mix of services will allow the operator and the investors to realize swift return on their investment, generate strong revenue and grow market share. The portfolio of these services must address the various needs across the operators' end user segments including basic residential, high speed residential, small to medium business, enterprise and government.

10.5.1 Classification of Services

The classification of services and applications can be segmented into three main groups (Table 10.4):

Table 10.4 Broadband services

Classification of services	Applications
Content services	Purchase of movies and music Leasing of movies and music Cultural services and entertainment: Video on demand(VoD) Events on demand TV channels and subscriptions On demand: news, sports, health, life style programs, etc. Substitutions: Performances like theatre, concerts, opera, cinema, etc. Lotteries and gambling: Online gambling Online betting Video transmission of the gambling event Gambling on automates Books, newspapers ,newsletters, journals: Books Online newspapers Newsletters Journals E-learning: Online education Online games Down loading and updating of gaming software Online games
Information retrieval (browsing, surfing)	Traditional free surfing Information storage (film, photos, other information)
Peer to peer and person to person	Video conference Exchange of personal content Exchange of downloaded content Surveillance at home for elderly/sick Different home services

- Content services
- Information retrieval and storage
- Person to person and peer to peer

10.5.2 Varying Terrain Conditions

The calculation of the coverage area and of the performance for WiMAX networks have to be based on the terrain conditions of the intended service area.

1. **Dense Urban:** This is the city centre where many of the businesses are located as well as high density multiple dwelling residential units. These areas represent a challenging propagation environment due to the multipath caused by the multi-storey buildings.

2. **Urban:** Immediately surrounding the city centre would be more businesses and moderate to high density multiple dwelling units. Average building heights may be lower but the propagation environment will be equally challenging.
3. **Suburban:** This describes areas with lower density housing, primarily single family dwellings, and fewer businesses. Average building heights are lower and, on average, structures are more spread out, thus creating a more favorable propagation environment.
4. **Rural:** Moving further from the city centre, homes are further apart resulting in significantly lower population density with scattered small businesses.

10.6 Cost/Revenue Optimization

10.6.1 Models

The economics of cellular systems can be viewed from the points of view of the different entities: subscribers, network operators, service providers, the regulator, and equipment vendors [4–6]. In this paper, although it is possible that for mobile multimedia networks the network operator and service providers can be different entities, we do not distinguish them. Thus we are considering the operator/service provider's point of view, whose primary bottom line is to improve his business.

In the cellular planning process, the objective of the operator is to determine an optimal operating point that maximizes expected revenues. Examples of major decisions affecting this include the type of technology to be used, the size of the cell, and the number of radio resources in use in each cell. It is important to identify the main components of the system's cost and revenues, in particular those that bear a direct relationship to either the maximum cell coverage distance or the reuse pattern. Here we consider the cost per unit area of a 2D system incurred during the system lifetime. The system is considered to have a transmission structure formed by a set of frequency carriers or channels (or the corresponding WiMAX sub-channels), each supporting a TDM frame structure. Each base station comprises a number of transceivers equal to the number of carriers assigned to the BS (or to the BS sector), which is assumed to be one in this study. That is, it is assumed as a simplification that one carrier will be sufficient per cell/sector.

System cost has two major parts: (a) capital costs (normal backhaul, cell site planning and installation), and (b) operating expenses (operation, administration and maintenance) [7, 8].

The capital cost is taken to consist of:

- A fixed part (e.g., licensing and spectrum auctions or fees)
- A part proportional to the number of BSs per kilometre or square kilometre (e.g., the installation costs of BSs including the cost of obtaining cell sites, the normal backhaul, and the cost of hardware and core equipment common to all), and

- A part proportional to the total number of transceivers per kilometre or square kilometre (e.g., the cost of the transceivers)

It is assumed that the cost of the connection between BSs and the Switching Centre, that is, the fixed part of the network (e.g., the cost of laying fibre), is not a fixed cost. Instead, we consider this to be proportional to the number of BSs, which can be true if, for example, the mobile operator's service is contracted from a fixed network operator.

The operating cost during a system's lifetime is taken to contain

- A part proportional to the number of BSs per kilometre or square kilometre,
- A part proportional to the number of transceivers per kilometre or square kilometre.

These costs will be incurred on an annual basis. A similar approach was followed in [3] for hierarchical WiMAX–Wi-Fi networks. However, here we follow the approach from [9].

The cost per unit area is given by:

$$C_{[/km^2]} = C_{fi}[\text{€/km}^2] + C_b \cdot N_{cell}/km^2. \quad (10.1)$$

where C_{fi} is the fixed term of the costs, and C_b is the cost per BS assuming that only one transceiver is used per cell/sector. The number of cells per unit area is given by:

$$N_{cell}/km^2 = \frac{2}{3 \cdot \sqrt{3} \cdot R^2}, \quad (10.2)$$

and the cost per BS is given by [9]:

$$C_b = \frac{C_{BS} + C_{bh} + C_{Inst}}{N_{year}} + C_{M\&O}, \quad (10.3)$$

where N_{year} is the project's lifetime (assumed here to be $N_{year} = 5$), C_{BS} is the cost of the BS, C_{bh} is the cost for the normal backhaul, C_{Inst} is the cost of the installation of the BS, and $C_{M\&O}$ is the cost of operation and maintenance.

The revenue per cell per year, $(R_v)_{cell}$, can be obtained as a function of the supported throughput per BS or sector (in the omnidirectional and sectorial cases, respectively), $R_{b-sup}[\text{kb/s}]$, and the revenue of a channel with a data rate $R_b[\text{kbits}]$, $R_{Rb}[\text{€/min}]$, by:

$$(R_v)_{cell} = \frac{N_{sec} \cdot R_{b-sup}[\text{kb/s}] \cdot T_{bh} \cdot R_{Rb}[\text{€/min}]}{R_{b-ch}[\text{kb/s}]}, \quad (10.4)$$

where N_{sec} is the number of sectors (one or three) T_{bh} is the equivalent duration of busy hours per day, and R_{b-ch} is the bit rate of the basic "channel". In the

tri-sectorial case, as one assumes that each sector has one different transceiver, there is a separate frequency channel available for it.

The revenue per unit area per year, $R_{v[\text{€/km}^2]}$, is obtained by multiplying the revenue per cell by the number of cells per unit area:

$$\begin{aligned} R_{v[\text{€/km}^2]} &= N_{\text{cell}/\text{km}^2} \cdot (R_v)_{\text{cell}} \\ &= N_{\text{cell}/\text{km}^2} \cdot \frac{N_{\text{sec}} \cdot R_{b\text{-sup}[\text{kbps}]} \cdot T_{bh} \cdot R_{R_b[\text{€/}\mu\text{v}]}}{R_{b\text{-ch}[\text{kbps}]}}. \end{aligned} \quad (10.5)$$

The (absolute) profit is given by

$$P_{[\text{€/km}^2]} = R_v - C, \quad (10.6)$$

from which, the profit in percentage terms is given by:

$$P_{[\%]} = \frac{R_v - C}{C} \cdot 100. \quad (10.7)$$

10.6.2 Hypothesis Without Relays

Following the approach form [9], it is hypothesised that project duration is of 5 years and there is a null discount rate; costs and revenues are taken on an annual basis. We consider 6 busy hours per day, 240 busy days per year [10], and a revenue/price of a 144 kb/s “channel” per minute (approximately corresponding to the price of 1 MByte, as $144 \times 60 = 8.640 \text{ kb} \approx 1 \text{ MByte}$), $R_{144[\text{€/min}]}$. The revenue per cell can be obtained as:

$$(R_v)_{\text{cell}[\text{€}]} = \frac{N_{\text{sec}} \cdot R_{b\text{-sup}[\text{kbps}]} \cdot 60 \cdot 6 \cdot 240 \cdot R_{144[\text{€/}\mu\text{v}]}}{144_{[\text{kbps}]}}. \quad (10.8)$$

Diverse assumptions for the price of the 144 kb/s channel (or a MByte of information) are considered for each scenario.

Two hypotheses are made for cost, denoted as A and B, as shown in Table 10.5. Hypothesis A is today’s situation. In the future, equipment prices will get lower with mass production, and spectrum bandwidth prices will also reduce, thereby making Fixed WiMAX systems more accessible. This future case is hypothesis B.

Assuming that the annual cost of a license is 50,000,000 € for $2 \times 24.5 \text{ MHz}$ bandwidth (UL & DL, $K = 7$), considering a total area of $91,391.5 \text{ km}^2$ as the area of Portugal, for example, the fixed cost per unit area is

$$C_{fi[\text{€/km}^2]} = \frac{50,000,000}{91,391.5} = 108.24 \approx 110 \text{ €/km}^2. \quad (10.9)$$

Table 10.5 Fixed WiMAX cost assumptions

Costs	Omnidirectional		Tri-sectored	
	A	B	A	B
C_{fi} (€/km ²)				
$K = 1$	15.71	15.71	47.14	47.14
$K = 3$	47.14	47.14	141.43	141.43
$K = 4$	62.86	62.86	188.57	188.57
$K = 7$	110.00	110.00	330.00	330.00
C_{BS} (€)	18,000	9,000	30,000	15,000
C_{Inst} (€)	10,000	1,000	18,000	1,500
C_{bh} (€)	5,000	2,500	5,000	2,500
$C_{M\&O}$ (€/year)	4,000	1,000	6,000	1,500

Table 10.6 Required spectrum bandwidth for different cell configurations and reuse patterns

K	BW (MHz)	
	Omnidirectional	Tri-sectored
1	3.5	10.5
3	10.5	31.5
4	14.0	42.0
7	24.5	73.5

If one considers that only one carrier will be allocated to each cell (or sector), if $K = 4$ or $K = 3$ then the available BW (and the respective cost) will be 4/7 or 3/7 of the value for $K = 7$, respectively.

Given that the total bandwidth, BW , is given by:

$$BW_{omni[MHz]} = N_{sec} \cdot K \cdot 3.5, \tag{10.10}$$

The necessary spectrum bandwidths can be obtained as in Table 10.6. Note that $N_{sec} = 1$ for omnidirectional cells and $N_{sec} = 3$ for sectorial cells.

10.6.3 Hypothesis and Assumptions with Relays

If the topology with relays from Chapter 9 is considered, the assumptions for costs with relays are the following:

(i) Cost for BS and RSs

- $C_{BS-omni} = 9,000$ €
- $C_{RS} = 9,000/5 = 1,800$ €
- $C_{BS-trisect} = 15,000$ €

In these cells there are three coverage areas with an area and the BS plus three RS need to guarantee the coverage for the whole area of cell. The equivalent cost for the “BS” meaning an average between the BS and the RS is given by:

$$C_{BS-equivalent} = \frac{(C_{BS} + 3C_{RS})}{3} \tag{10.11}$$

ii) Cost for backhaul

The cost for backhaul is the same as in case of without relays for RSs and BS that is:

$$C_{bh-equivalent} = \frac{1}{3}C_{bh} \quad (10.12)$$

for each hexagonal coverage area (as backhaul is only needed for the central coverage area of the BS).

iii) Installation Cost

The cost for installation is the same for every BS and RS. It is four times the installation cost of a BS, C_{inst} . Hence, we need to multiply C_{inst} by $1/3$ to obtain the installation cost for each coverage area. It is given by:

$$C_{inst-equivalent} = \frac{4}{3}C_{inst} \quad (10.13)$$

iv) Maintenance and operation cost

We assume that the maintenance and operation cost for the BS are the same as in the case without relays and the ones for the RS are $1/2$. It is given by

$$C_{M\&O-equivalent} = \frac{(C_{M\&O} + \frac{3}{2}C_{M\&O})}{3}. \quad (10.14)$$

These equations may be applied to the topology with relays and omnidirectional BSs. In this case the following parameters were used, Table 10.7:

- $C_{BS-omni} = 9,000 \text{ €}$ and $C_{RS} = 1,800 \text{ €}$ (i.e., $C_{BS-equivalent} = 4,800 \text{ €}$)
- $C_{inst} = 1,000 \text{ €}$ (i.e., $C_{inst-equivalent} = 1,333.33 \text{ €}$)
- $C_{bh} = 2,500$ (i.e., $C_{bh-equivalent} = 833.33 \text{ €}$)
- $C_{M\&O} = 1,000 \text{ €}$ (i.e., $C_{M\&O-equivalent} = 833.33 \text{ €}$)

For the tri-sectored BS antennas the parameters are the following, Table 10.7 (note that the costs for the backhaul, and maintenance and operation are the same):

- $C_{BS-tri-sect} = 15,000 \text{ €}$ and $C_{RS} = 1,800 \text{ €}$ (i.e., $C_{BS-equivalent} = 6,800 \text{ €}$)
- $C_{inst} = 1,500 \text{ €}$ (i.e., $C_{inst-equivalent} = 2,000 \text{ €}$)
- $C_{bh} = 2,500$ (i.e., $C_{bh-equivalent} = 833.33 \text{ €}$)
- $C_{M\&O} = 1,000 \text{ €}$ (i.e., $C_{M\&O-equivalent} = 833.33 \text{ €}$)

Table 10.7 Costs with relays for omnidirectional ($K = 3$) and tri-sectored ($K = 1$) BS antennas

Costs	Omnidirectional $K = 3$	Tri-sectored $K = 1$
$C_{fl}(\text{€/km}^2)$	47.14	47.14
$C_{BS}(\text{€})$	4,800	6,800
$C_{inst}(\text{€})$	1,333.33	2,000
$C_{bh}(\text{€})$	833.33	833.33
$C_{M\&O}(\text{€/year})$	833.33	833.33

It should be noted that

- With sectorization the cost for the licence with $K = 1$ are equal to the cost for the licence with omnidirectional BS antenna and $K = 3$.
- With tri-sectorization some costs are higher (e.g., BS and its installation). However, higher costs are compensated with the higher revenues. Because throughput is higher (mainly due to the difference on the sub-frame format), a gain of $\frac{3/5}{1/3} = \frac{9}{5} = 1.8$ occurs, which compensated the lowest value of the frame throughput.

Besides, it is worthwhile to note that

- For $K = 3$ with relays UL traffic is $\sim \frac{1}{5}$ times the DL traffic, hence revenues are lower;
- For $K = 1$ with relays and sectorization, UL traffic is $\frac{3}{7} \times$ DL traffic, hence revenues may be relevant.

10.6.4 Optimization and Profit Without Relays

In seeking profit optimisation, revenues should be maximised with respect to costs. Under hypothesis B, which corresponds to the lowest cost case, and for $K = 7$, the variation of the cost and revenue in $\text{€}/\text{km}^2$ with R is depicted in Figs. 10.5 and 10.6, for omnidirectional and tri-sectored cells respectively. The revenue curves were obtained for $R_{144}[\text{€}/\text{min}] = 0.0025$ (which approximately corresponds to the price per MByte [5]). Note that the UL curves for the cases with omnidirectional BS antennas and suchannelisation and tri-sectorization are superimposed for distances up to

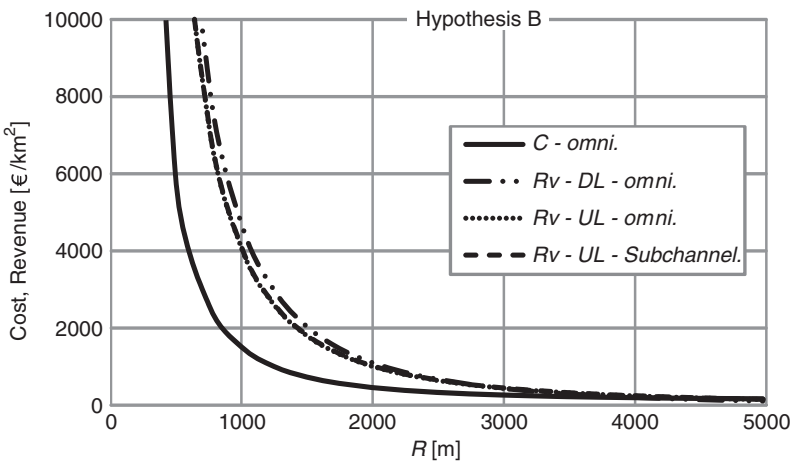


Fig. 10.5 Cost and revenues versus R for $K = 7$ under hypothesis B, for the omnidirectional case

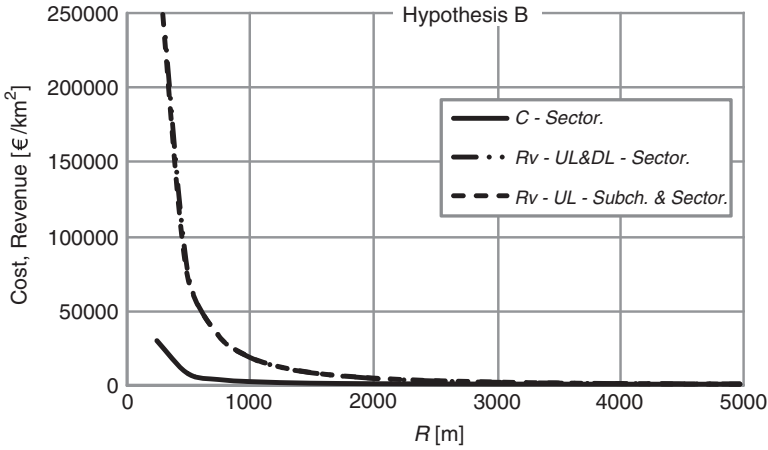


Fig. 10.6 Cost and revenues versus R for $K = 7$ under hypothesis B, for the tri-sectored case

3,000 m. With tri-sectorial BS antennas, as there is three time more available resources the revenues increase significantly.

In order to optimize the broadband wireless access network, it is important to analyse the profit per unit area. However, it is not sufficient to compute the absolute profit because, as is shown in Figs. 10.5 and 10.6, a certain level of profit may correspond to different values of cost. For example, cost is higher for tri-sectorial cells; hence, revenue needs to be higher to obtain the same profit.

It is worthwhile to note that, with tri-sectorial BS antennas, higher revenues are expectable not only due to the interference mitigation caused by the use of directional antennas but also because three channels are now available in the cell, one for each sector, leading to an higher supported throughput per km^2 .

We have obtained results for the profit in percentage for two values of the price per MByte $R_{144}[\text{€/min}] = 0.005$ and 0.010) in hypothesis A, corresponding to higher costs, in Figs. 10.7 and 10.8 respectively.

It is particularly evident that profit increases as the price per MByte increases; nevertheless, the curves keep the same shape and behaviour. For tri-sectorial cells, as there is three carriers available in the cell, the profit in percentage is almost three times higher than the one for the case of omnidirectional cells for a considerable range of coverage distances, typically lower than 1,800 m, which only reaches $\sim 375\%$. For coverage distances larger than this value, this relative difference is only kept if sub-channelisation is considered.

In hypothesis B (lower network cost), the advantage of using a tri-sectored configuration becomes even more evident for the shortest propagation distances of up to 1,250–1,500 m (see Fig. 10.9). Although the required bandwidth in each FDD link is three times higher, the profit in percentage terms is now more than three times higher than the one with omnidirectional cells. Figure 10.9 presents an example for $R_{144}[\text{€/min}] = 0.005$ in hypothesis B, where it is clear that profit values

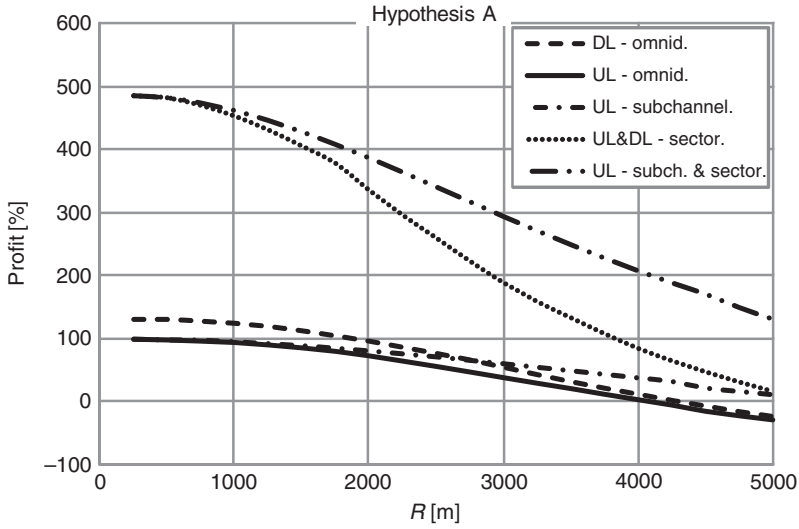


Fig. 10.7 Profit in percentage terms versus R for $K = 7$ under hypothesis A, $R_{144[\text{€}/\text{min}]} = 0.005$

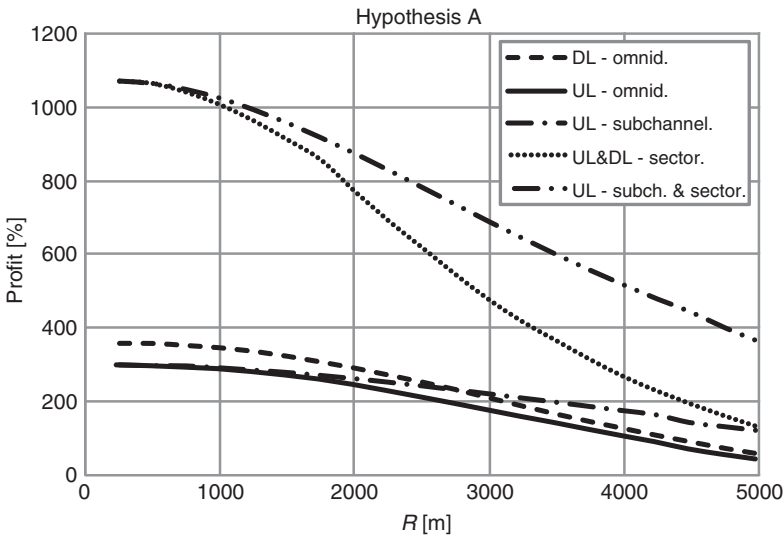


Fig. 10.8 Profit in percentage terms versus R for $K = 7$ under hypothesis A, $R_{144[\text{€}/\text{min}]} = 0.010$

are more than four times the values in Fig. 10.7. As costs are lower, even with a price per MByte of only $R_{144[\text{€}/\text{min}]} = 0.005$ the profit in percentage terms may exceed 1,500%. Although the curves are not presented here, even for $R_{144[\text{€}/\text{min}]} = 0.0025$, the values of the profit are more than twice the ones from Fig. 10.7.

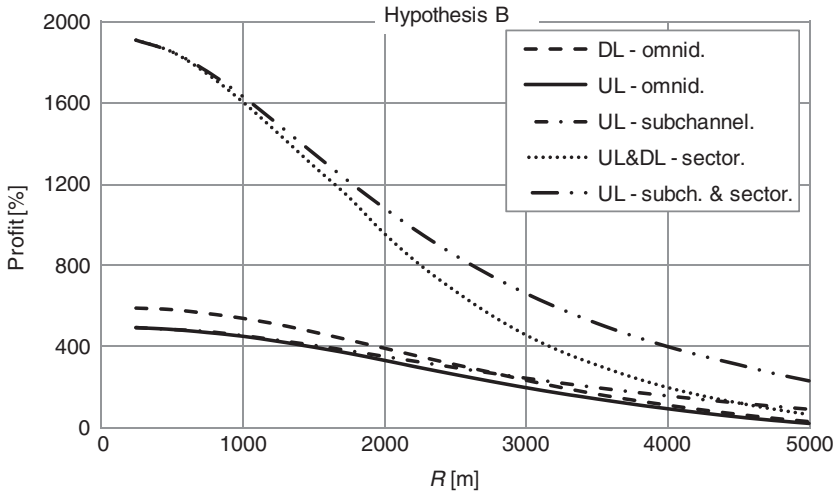


Fig. 10.9 Profit in percentage terms versus R for $K = 7$ under hypothesis B, $R_{144[\text{€}/\text{min}]} = 0.005$

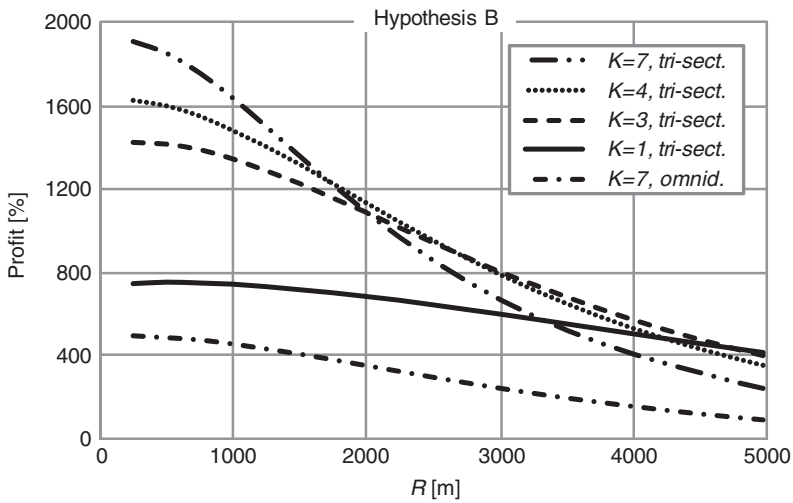


Fig. 10.10 Profit in percentage terms versus R for different K 's under hypothesis B, with tri-sectored cells for the UL where $R_{144[\text{€}/\text{min}]} = 0.005$

A comparison between $K = 7$, $K = 4$, $K = 3$ and $K = 1$ is presented in Fig. 10.10 (for tri-sectored cells in the UL and $R_{144[\text{€}/\text{min}]} = 0.005$). Sub-channelisation is considered, as it is specified on the UL. Note that in the tri-sectorial case the required bandwidth in each FDD link is three times higher. For example, for $K = 3$,

it increases from 10.5 to 31.5 MHz. The consideration of a reuse pattern $K = 7$ is ideal in terms of interference mitigation, although $K = 1$, $K = 3$ and $K = 4$ may also be interesting possibilities for coverage distances between 1,500 and 1,800 m. Note, however, that, from the spectrum regulation point of view, to use $K = 7$ and tri-sectorized cells seems to be infeasible, as a spectral bandwidth of 73.5 MHz is needed.

With $K = 1$ and $K = 3$, the use of omnidirectional configurations cannot be supported as the throughput on the outer coverage ring of the cell reaches 0 Mb/s and full cell coverage is not guaranteed. Although the curve is not presented here, in the omnidirectional case, with $K = 4$, profits of 260–290% are achieved in the UL (and of 370–420% in the DL) for coverage distances up to 1,500 m ($R_{144}[\text{€/min}] = 0.005$). Only with $K = 7$ higher profits are achieved with omnidirectional cells, of the order of 400–490% in the UL, as shown in Fig. 10.10 (where sub-channelisation is considered), and 470–580% in the DL. However, this compares poorly with the values varying from 1,400% to 1,900% for $K = 3$, 4 and 7 with tri-sectorized cells.

The cases $K = 1$, $K = 3$, $K = 4$ (all with tri-sectorized cells), and $K = 7$ (with omnidirectional cells) correspond to a spectrum bandwidth of 10.5, 31.5, 42.0 and 24.5 MHz, respectively. $K = 4$ and $K = 3$ with tri-sectorial BS antennas seem to be the optimum choices, with an advantage for the choice of $K = 3$, as only 75% of the bandwidth is needed. With $K = 1$ and tri-sectorized cells the profit in percentage terms is higher than with $K = 7$ and omnidirectional cells, with an additional advantage: only 43% of the bandwidth is needed. Besides, it is worthwhile to note that, for $K = 1$ and coverage distances longer than 4,000 m, the values for the profit in percentage terms become comparable to ones with $K = 4$ and $K = 3$ (tri-sectorized cells), that is, for sparse BS deployments in low density user environments $K = 1$ may be a solution.

If network costs are higher (hypothesis A), the relative behaviour is basically the same as in hypothesis B. Under the price per MByte of $R_{144}[\text{€/min}] = 0.010$, the profit may reach values of somewhere between 780% and 1,060%. It seems that the relative disadvantage with $K = 7$ and omnidirectional cells becomes less evident, as shown in Fig. 10.11 under hypothesis A (in comparison to Fig. 10.10).

With $K = 1$ and tri-sectorized cells, the profit in percentage terms is again higher than with $K = 7$ and omnidirectional cells. However, for the longest coverage distances, no advantage of using $K = 1$ can be found in comparison to $K = 3$ or 4 anymore.

In terms of the choice of optimum coverage distance, from analysis of the results in Figs. 10.5 and 10.6 it is evident that network cost strongly increases if the coverage distance decreases, particularly for the lowest coverage distances. Investigating the profit in percentage terms, it can be observed that significant falls occur for coverage distances of higher than 1,500 m. Hence coverage distances of around 1,000 m might be chosen as optimum, as they maximize profit in percentage terms while keeping costs acceptable. A daily equivalent operation in saturated conditions over 6 h has been assumed, which is only valid if the offered traffic is high enough in this time span. Otherwise, revenue will be lower, and low costs will definitively reduce the possibility of losses.

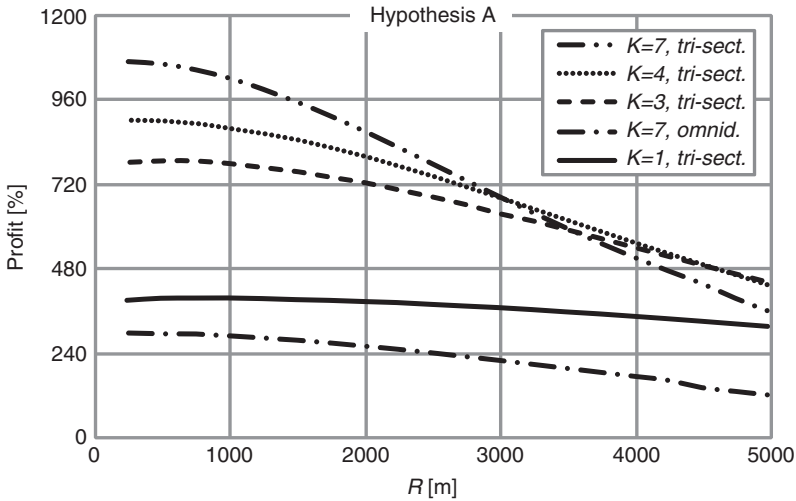


Fig. 10.11 Profit in percentage terms versus R for different K 's under hypothesis A, for the UL where $R_{144}[\text{€}/\text{min}] = 0.010$

10.6.5 Optimization and Profit with Relays

10.6.5.1 DL Analysis with $K = 3$ and $K = 1$

In seeking profit optimisation, revenues should be maximised with respect to costs. By using Table 10.7 (but also Table 10.6), and the results for the supported throughput from Chapter 9, we obtained the curves for costs, revenues and profit in percentage. The costs and revenues with relays ($K = 3$, omnidirectional BS antenna), in $\text{€}/\text{km}^2$, are depicted in Figs. 10.12 and 10.13, for $R_{144} = 0.0025$ and $0.005 \text{ €}/\text{min}$, respectively.

In order to optimize the broadband wireless access network, it is important to analyse the profit per unit area. However, it is not sufficient to compute the absolute profit because, as is shown in Figs. 10.12 and 10.13, a certain level of profit may correspond to different values of cost. For example, cost is higher for tri-sectorial cells; hence, revenue needs to be higher to obtain the same profit. This justifies the need to represent the profit in percentage, as defined by (10.7). The operator's/ services provider's goal is to optimise this profit in percentage.

Results are obtained with relays and $K = 1$ (tri-sectorial BS antennas) and $K = 3$ (omnidirectional BS antennas) in the DL case. Figure 10.14 presents the results for $R_{144} = 0.0025 \text{ €}/\text{min}$ while Fig. 10.15 presents the case for $R_{144} = 0.005 \text{ €}/\text{min}$. The case without relays ($K = 3$) is also presented, for comparison purposes.

It is clear that the use of relays without sectorization in the BS leads to a lower profit ($K = 3$). Even the use of sectorization (an example is presented for $K = 1$) does not enable to achieve larger profit (note that for $K = 1$ interference poses an extra

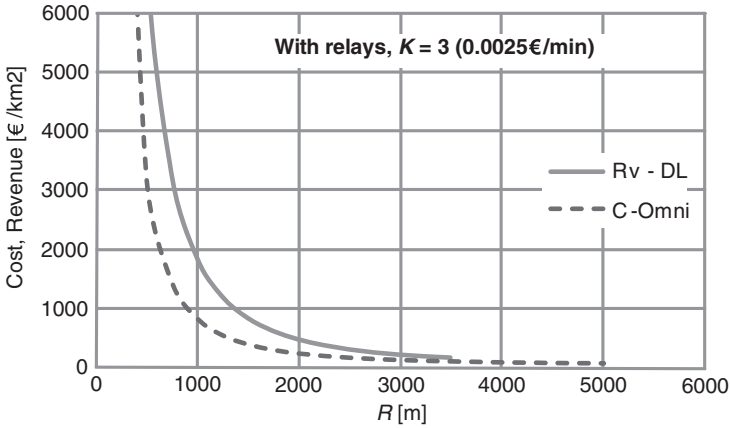


Fig. 10.12 Cost and revenues with relays ($K = 3$, omnidirectional BS antenna) for a price per MB $R_{144} = 0.0025$ €/min, in the DL

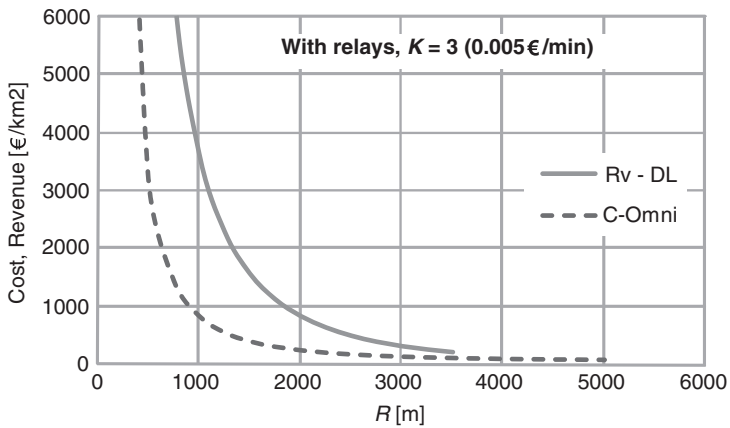


Fig. 10.13 Cost and revenues with relays ($K = 3$, omnidirectional BS antenna) for a price per MB $R_{144} = 0.005$ €/min, in the DL

limitations; hence, results with $K = 3$ may be checked with sectorization). The optimum (maximum) values occur for coverage distances up to 1,000 m.

10.6.5.2 UL Analysis with $K = 3$ and $K = 1$

We also have performed analysis for UL with $K = 3$ and $K = 1$. By using the Table 10.7 (but also Table 10.6), and the results for the supported throughput from Chapter 5, we obtained the curves for the costs, revenues and profit in percentage.

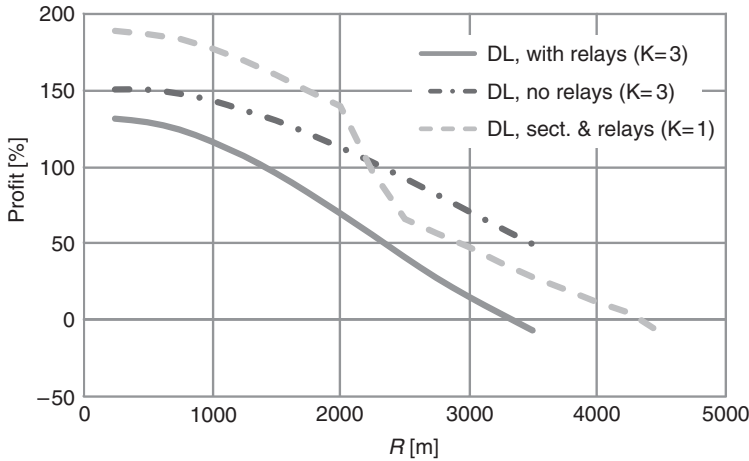


Fig. 10.14 Profit in percentage for a price per MB $R_{144} = 0.0025$ €/min, in the DL

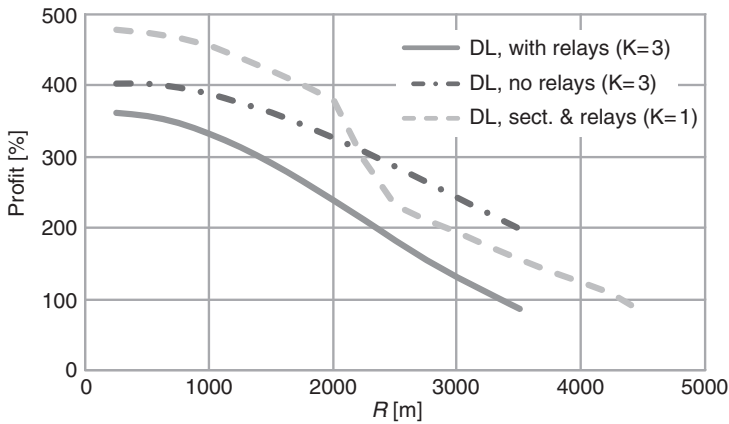


Fig. 10.15 Profit in percentage for a price per MB $R_{144} = 0.005$ €/min, in the DL

The costs and revenues with relays ($K = 3$, omnidirectional BS antenna), in €/km², are depicted in Figs. 10.16 and 10.17, for $R_{144} = 0.0025$ and 0.005 €/min, respectively. It is shown that, in the UL, for $K = 3$ and omnidirectional BS antennas there is no profit, that is, revenues are always lower than costs.

Results for the profit in percentage, as defined by Eq. (10.7), are obtained with relays and $K = 1$ (tri-sectorial BS antennas) and $K = 3$ (omnidirectional BS antennas) in the UL case. Figure 10.18 presents the results for $R_{144} = 0.0025$ €/min while Fig. 10.19 presents the case for $R_{144} = 0.005$ €/min. The case without relays ($K = 3$) is not presented, as it is impossible to obtain results with such low reuse pattern with no relays (and no sectorization, too).

In the UL, with relays, only the use of sectorization (an example is presented for $K = 1$) enables to achieve positive profit in percentage only for $R_{144} = 0.005$ €/min

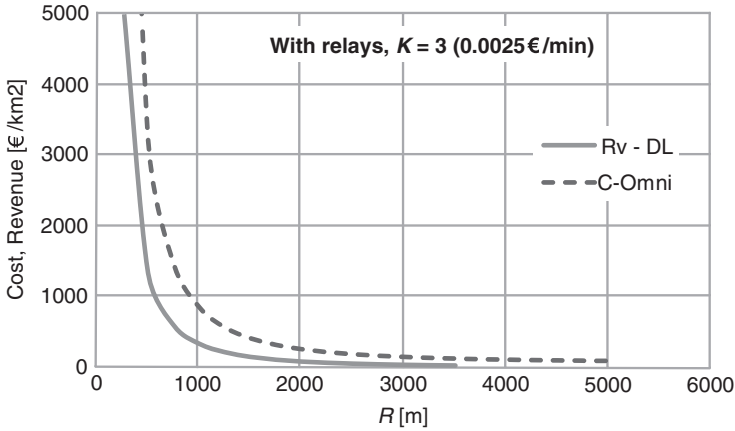


Fig. 10.16 Cost and revenues with relays ($K = 3$, omnidirectional BS antenna) for a price per MB $R_{144} = 0.0025$ €/min, in the UL

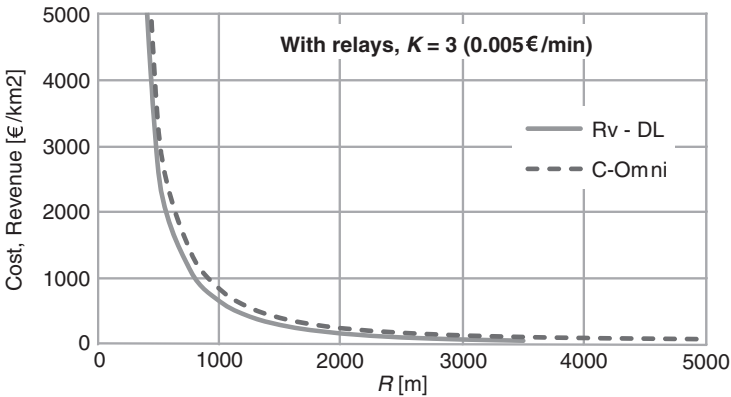


Fig. 10.17 Cost and revenues with relays ($K = 3$, omnidirectional BS antenna) for a price per MB $R_{144} = 0.005$ €/min, in the UL

(nor for $R_{144} = 0.0025$ €/min). With omnidirectional BS antennas (an example is presented for $K = 3$) a positive profit is not achievable in any of the prices.

As for the DL, the maximum values occur for coverage distances up to 1,000 m.

10.7 Conclusions

Appropriate business models are essential to establish the business case for WiMAX networks. This Chapter started by covering general aspects about the business models for WiMAX and then addressed the cost/revenue optimization

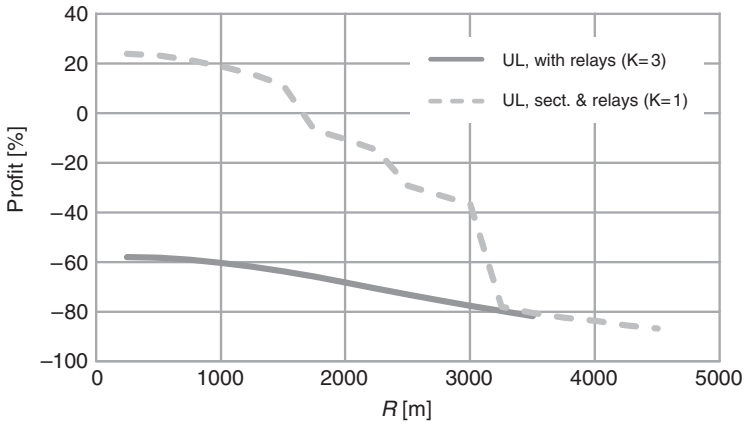


Fig. 10.18 Profit in percentage for a price per MB $R_{144} = 0.0025$ €/min, in the UL

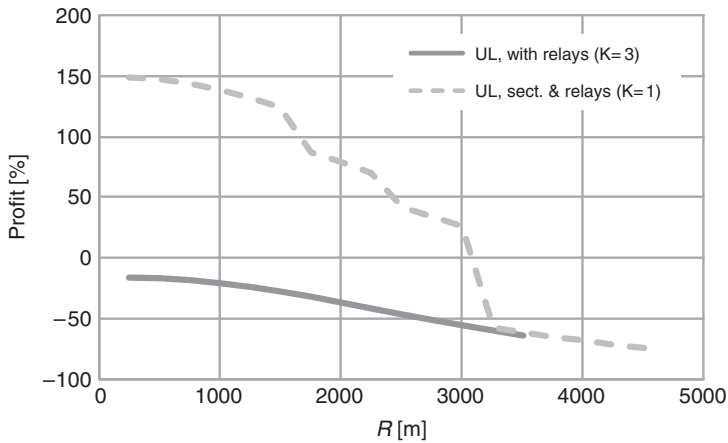


Fig. 10.19 Profit in percentage for a price per MB $R_{144} = 0.005$ €/min, in the UL

for these networks, for cellular configurations without and with relays. From an undertaken cost-benefit analysis, one conclusion of this work is that given today's hypothesis of price per MByte of information transfer of somewhere between 0.0025 € and 0.010 €, it is clear that, without considering the use of relays, the choice of reuse patterns 3 or 4 with sectorial cells is preferable to the use of omnidirectional cells with reuse pattern of 7, as three times more resources are available in each cell. Besides, in nowadays networks, if there is a need for sparse BS deployments whilst reducing costs, $K = 1$ may be a solution, as it presents higher profit for the longest coverage distances. In future networks, when costs will be lower, the advantage of sectorization is kept and will drive the deployment of

tri-sectorization forward. Nevertheless, in this case $K = 1$ will not be advantageous with tri-sectorization for the longest coverage distances anymore.

It has also been concluded in this paper, driven by our analysis as well as other observations, that cell radii in the range 1,000–1,500 m might be chosen. This range corresponds to a profit, in percentage terms, of near to the maximum achievable, while keeping costs acceptable.

The WiMAX cost-benefit optimization is also explored for the case where relays are used to help on improving coverage while mitigating the interference. Results show that the use of relays with no sectorization in the BS leads to a lower profit ($K = 3$). Also the use of sectorization (an example is presented for $K = 1$) does not enable to achieve larger profit. The optimum (maximum) values occur for coverage distances up to 1,000 m. In the DL, when the price per MB, R_{144} , increases from 0.0025 €/min to 0.005 €/min the profit increases more than 100%.

Suggestion for future work on the optimization of cellular configurations with relays is to explore sectorization for $K = 3$ (as interference is mitigated for larger reuse patterns), consider different assumptions for the prices of the relays, and mainly to jointly achieve the profit curves joining together the UL and DL contributions for the supported traffic.

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