COMPETITIVE POTENTIAL OF WIMAX IN THE BROADBAND ACCESS MARKET: A TECHNO-ECONOMIC ANALYSIS

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Abstract

WiMAX radio networks have been proposed as an alternative technology to provide services for the fixed broadband access market, currently dominated by DSL and cable modem systems. In this paper, the economic feasibility of WiMAX network deployments is analyzed with a quantitative techno-economic model. The model is used to assess the coverage, capacity, and cost characteristics of WiMAX systems in contrast to the forecasted evolution of the highly competitive marketplace experiencing increasing data rates and decreasing tariffs.

The results of the analysis show that WiMAX network deployments can be profitable in dense urban areas as well as in rural areas where the availability of other alternatives is limited. Low profitability can be expected in urban and suburban areas with medium population densities and good availability of other access network alternatives. The most critical success factors regarding the profitability of WiMAX network deployments are the CPE price and broadband tariff levels. The performance of the systems appears to be suitable for the broadband traffic demands of today, but the emergence of services requiring higher data rates may turn out to be problematic for WiMAX operators.

1. Introduction

Digital subscriber line (DSL) technologies have become the most popular broadband access method globally, constituting more than 60% of the broadband lines in OECD countries [1], and about 80% of broadband lines in Europe [2]. The dominance of DSL is visible in Figure 1, illustrating the broadband penetration and market shares of different technologies in the 25 EU countries.

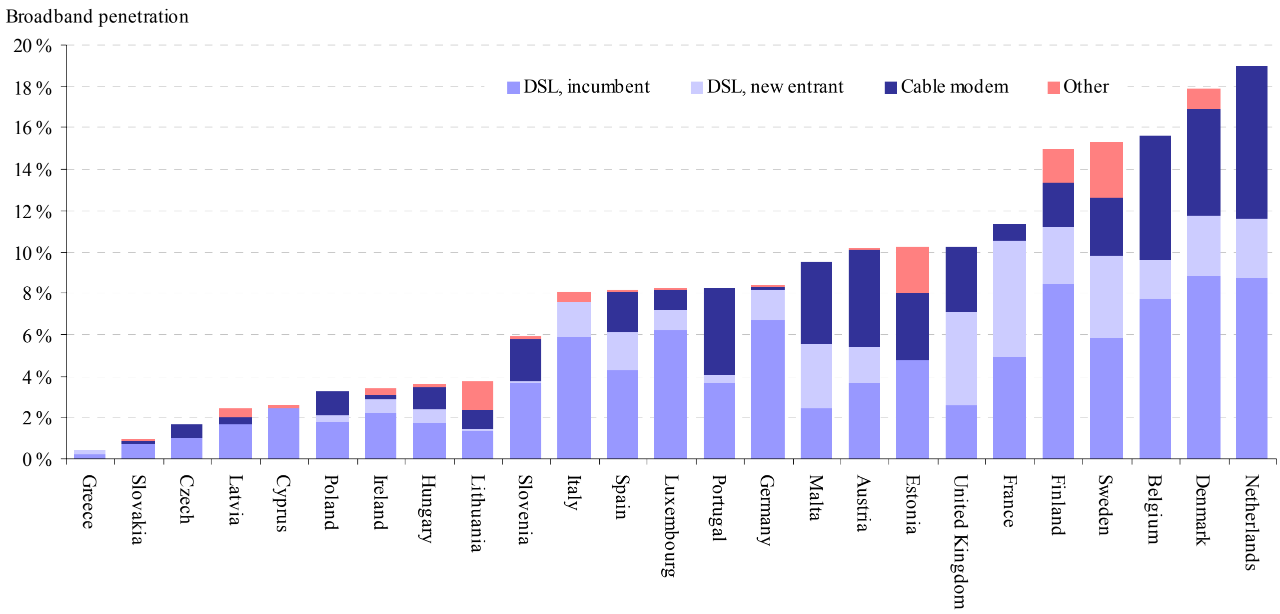


Figure 1: Broadband penetration in the EU countries, by technology, January 2005 [2]

In January 2005, the average broadband penetration level in the EU countries was 8.6 %, calculated as broadband lines per number of inhabitants. Netherlands, Belgium, and the Nordic countries had clearly higher penetration levels than others, whereas the large Western European countries of Germany, France, U.K, Italy, and Spain were close to the average penetration level. In many of the new EU countries, the penetration levels were clearly below the average.

Figure 1 illustrates also two different types of competition existing in the broadband access market: service-based and facilities-based competition. Service-based competition takes place when new entrant operators utilize the incumbent's existing network infrastructure and offer DSL services by means of fully unbundled lines, shared access lines, bitstream access, or resale. In facilities-based competition, the new entrants build and operate their own access network infrastructure, based on e.g. cable modem systems or some other technology.

As visible in the figure, the level of both service and facilities-based competition varies significantly between the EU countries. On average, the market share of new entrants utilizing DSL has grown consistently during the past years, and in the beginning of 2005 over a third of the active DSL lines were provided by new entrants [2]. The market share of cable modem systems has decreased in the past years, but is still significant in many countries, especially in the ones experiencing higher broadband penetration levels. The market share of other technologies has not become significant, and is visible mainly in the Nordic and Baltic countries.

Cable modem services are currently offered by cable-TV operators and are generally not open for service-based competition. Thus, for a company desiring to enter the broadband access market, the viable choices are to either provide DSL services over the incumbent's telephone network infrastructure, or to build a new access network by utilizing some alternative technology.

For many years already, fixed wireless access networks have been proposed as an alternative to DSL and cable networks. By far, the systems have failed to reach the mass markets, largely due to lack of standards and interoperability, low economies of scale and resulting high prices of equipment. Recently published standards from the IEEE 802.16 working group and interoperability certification by the WiMAX Forum are, however, expected to improve the prospects of the systems in the broadband access market.

Initial WiMAX deployments will provide fixed broadband access to households and businesses, but some have claimed the technology to compete also with IEEE 802.11-based WLANs and 3G mobile systems in the future. In many cases, WiMAX has received overly optimistic appraisals by the industry press, and there is an obvious need for an objective analysis of its competitive potential.

2. WiMAX technology

2.1 Network architecture

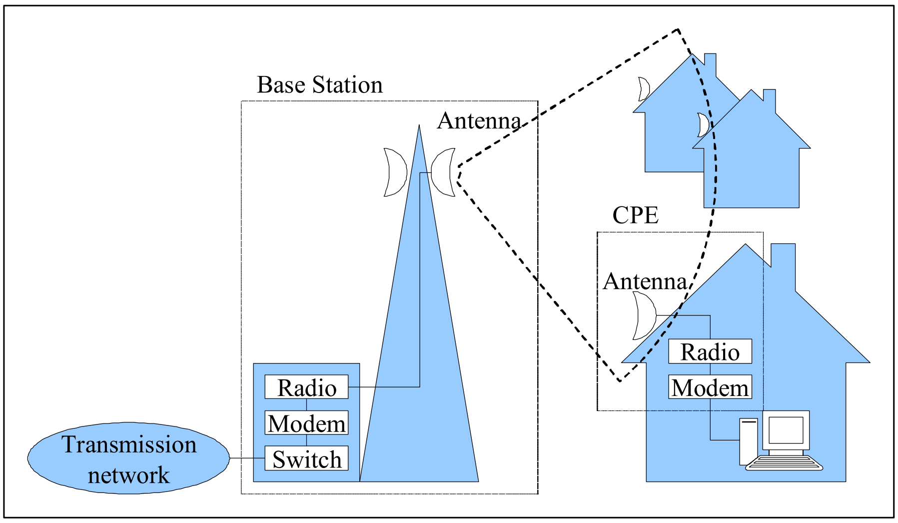


Figure 2: Point-to-multipoint FWA network architecture

Figure 2 illustrates a typical fixed wireless network (FWA) network architecture. FWA networks are typically based on a point-to-multipoint topology, consisting of number of subscriber stations, i.e. customer premises equipment (CPE), connected to central base stations (BS), possibly via repeater stations. Base stations provide sectorized coverage areas using antennas with beamwidths of e.g. 60, 90, or 120 degrees, effectively multiplying the capacity of the BS cell. CPEs may have either separate directional antennas requiring outdoor installation or omni-directional antennas integrated to the indoor CPE unit.

2.2 Standards and interoperability

Interoperability between system manufacturers allows e.g. CPEs from one vendor to be used in a network using BSs from another, thus reducing lock-in risks for operators and allowing standard components to be manufactured in large quantities and lower prices. The IEEE 802.16 standards and WiMAX certification program are the most essential drivers of interoperable FWA systems.

The IEEE Standard 802.16-2004 [3] standard specifies the air interface for fixed broadband wireless access systems. The standard does not specify a single inter-operable FWA system, but includes a plethora of options for the equipment manufacturers to choose from. The standard includes separate physical layer specifications for single carrier (SC), orthogonal frequency division multiplexing (OFDM), and orthogonal frequency division multiple access (OFDMA) systems, operating on various licensed and license-exempt bands between 2 and 60 GHz. Furthermore, system vendors can choose between FDD and TDD duplexing schemes, various channel bandwidths, and point-to-multipoint and mesh network topologies. For a more detailed introduction to the details of the IEEE 802.16 standard, see e.g. [4] and [5].

WiMAX Forum [6] was founded in 2001 to promote and certify compatibility and interoperability of broadband wireless access systems from different equipment manufacturers. To drive interoperability, WiMAX Forum has specified a number of system profiles, i.e. subsets of options from the IEEE 802.16-2004 standard that have to be implemented by the equipment manufacturers in order to get their systems certified. The certification process was launched in mid-2005, and first OFDM-based WiMAX-certified products are expected to be available at the beginning of 2006.

2.3 Available frequency bands

The performance of WiMAX networks is strongly dependent on the available frequency bands for the systems. Viable deployments require tens of MHz's of spectrum per operator, preferably on the lower end of the radio spectrum to achieve better range and coverage. The first WiMAX-certified products will be operating in the licensed 3.5 GHz frequency band, followed by systems for both the 2.5 GHz licensed band as well as the 5.8 GHz license-exempt band (Table 1).

Table 1: Initial frequency bands available for WiMAX-certified systems

Frequency band	**2.5 GHz**	**3.5 GHz**	**5.8 GHz**
Allocation size	USA: 195 MHz	Europe (typical): 190 MHz	USA: 125 MHz
Licensed / Unlicensed	Licensed	Licensed	Unlicensed
Expected availability in 2005-2007	Canada, USA, Central and South America, Asia Pacific	Canada, Central and South America, EMEA, Russia, Asia Pacific	Global
Transmission power limits	U.S.: +53 dBm EIRP	Varies between countries	US: +36 dBm EIRP
Typical spectrum allocation per operator	U.S.: 3 x 5.5 MHz + 6 MHz	Europe: 2 x 21-28 MHz	No licenses
Suitable channel bandwidths	5.5 MHz, 3 MHz	1.75 MHz, 3.5 MHz, 7 MHz	10 MHz

In addition to the three initial bands, spectrum for FWA networks is available in many frequency bands above 10 GHz. In most European countries, large amounts of spectrum have been allocated around the 26 GHz, 28 GHz, and 40 GHz frequency bands. The characteristics of these bands are very different from the sub-10 GHz bands, requiring strict line-of-sight link conditions and experiencing higher path loss and rain fading. On the other hand, spectrum allocations are typically large, in the order of 100-200 MHz per operator, allowing higher data rates to be offered.

2.4 Capacity and coverage performance

Radio access networks are dimensioned to provide both sufficient coverage and capacity to the service area. Accordingly, network deployments can be either coverage or capacity limited. In coverage limited networks the capacity demand of the service area can be fulfilled with a minimum number of BS cells optimized for maximum range. In a capacity limited case, additional BS cells and sectors are required to fulfill the capacity demand.

The capacity of a single FWA base station sector depends on the channel bandwidth and the spectral efficiency of the utilized modulation and coding scheme. WiMAX systems take advantage of adaptive modulation and coding, meaning that inside one BS sector each CPE may use the most suitable modulation and coding type irrespective of the others. CPEs experiencing higher path loss have to use more robust and less effective modulation types than CPEs with better link conditions. The most robust modulation type in use is BPSK, whereas 64-QAM is the most efficient one, providing maximum data rates from less than 3 Mbps to above 25 Mbps in a system using typical 7 MHz channels.

To account for the adaptive modulation, the capacity of a single BS sector is calculated as the average of link capacities of all the CPEs in the sector area. For example, in a sector dimensioned for maximum range, approximately 69% of the users have to utilize the more robust modulation types

BPSK and QPSK, decreasing the average sector capacity to only 39% of the maximum link capacity. This tradeoff between relative sector range and capacity is illustrated in Figure 3, separately for deployments using indoor and outdoor CPEs. The actual cell range depends on the utilized frequency band, propagation environment, and system performance characteristics.

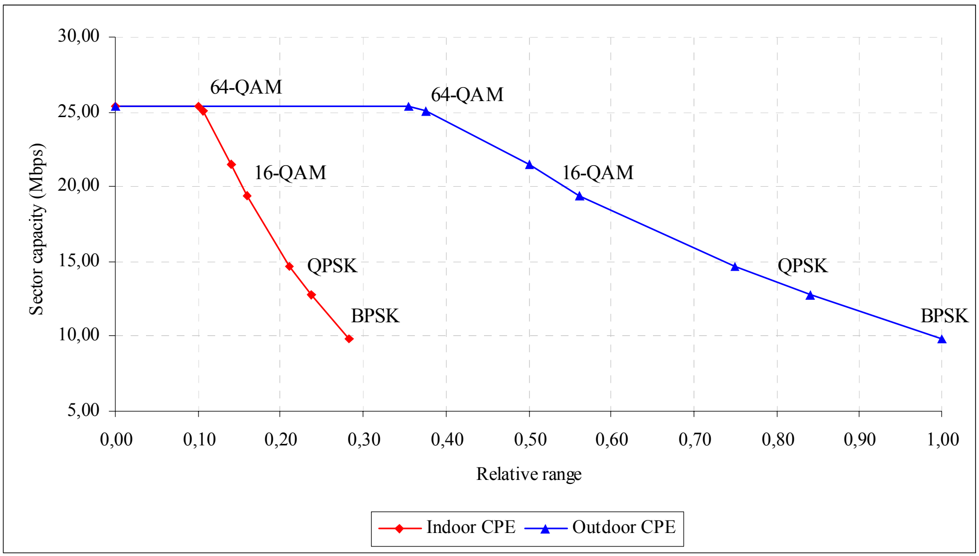


Figure 3: Average sector capacity as a function of cell range for WiMAX systems using indoor / outdoor CPEs (Assuming channel bandwidth = 7 MHz, path loss exponent = 4, receiver sensitivity requirements as in [3], and an excess path loss of 22dB for indoor CPE deployments)

For WiMAX systems operating on the sub-10 GHz frequency bands, service offerings with data rates above 2 Mbps may become problematic. Although the average data rate in a coverage-limited BS sector would be around 10 Mbps, the subscribers in the cell edge utilising BPSK modulation are capable of transmitting/receiving at data rates of less than 3 Mbps. This means that 4 Mbps services can be offered only for subscribers located sufficiently near the base station, utilizing e.g. 16-QAM or 64-QAM modulation. The situation is very similar to DSL networks, where subscribers having too long local loops from their premises to the telephone exchanges are not able to utilize data rates in excess of 1 or 2 Mbps. Because of this capacity limitation, e.g. high-quality video services are not viable.

A detailed introduction and information about the design and performance of FWA networks can be found in e.g. [7].

3. Techno-economic model and assumptions

For the purposes our analysis, an advanced techno-economic model was created, utilizing an Excel™-based tool created in the European research projects TONIC [8] and ECOSYS [9]. The model takes into account various technology and market related parameters and assumptions, and gives basic profitability measures such as net present values (NPV) and internal rates of return (IRR) as outputs. The required inputs and the internal logic of the model are illustrated in Figure 4.

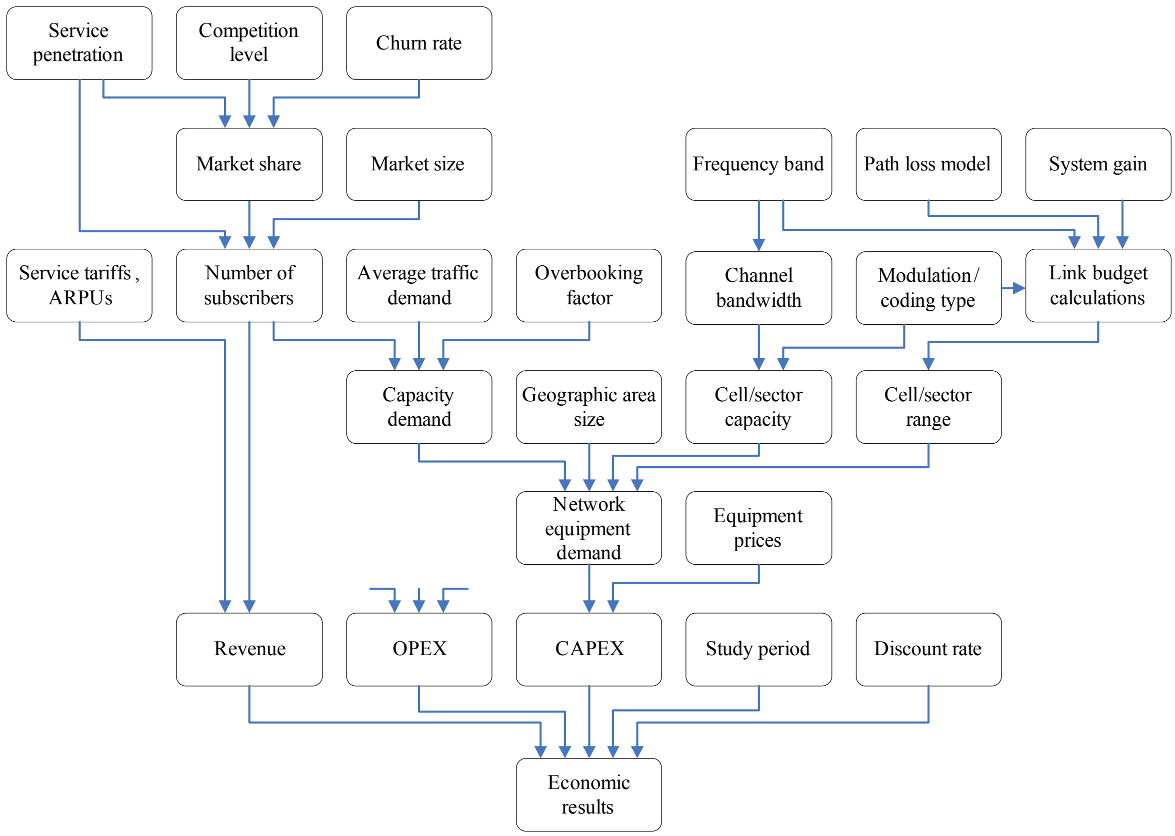


Figure 4: Model for techno-economic analysis of WiMAX networks

The model is used to analyze a 3.5 GHz WiMAX-based network deployment, providing fixed broadband services for residential customers and small-to-medium sized enterprises (SMEs). All the calculations are done over a five-year study period (2006-2010) using a discount rate of 10%, and the rest value of the network in the end of the year 2010 is assumed to be the depreciated value of cumulative investments. The other inputs are discussed in more detail in the following sections.

3.1 Area types

For the analysis, we have separated between urban, suburban, and rural areas, having different household and business densities, and experiencing different levels of competition. In each area, 50.000 households and 5.000 SME offices are assumed to exist. In the urban areas, both DSL and cable networks are assumed to provide full coverage, whereas in the suburban areas the DSL availability is assumed to be 95% and cable to cover 50% of the DSL area. In rural areas, the DSL availability is 75% and no cable services are available.

Table 2: Characteristics of area types

Area type	Urban	Suburban	Rural
Area size (km2)	10 … 50	100 … 500	2500 … 10000
Household density (1/km2)	5000 … 1000	500 … 100	20 … 5
Business density (1/km2)	500 … 100	100 … 20	2 … 0.5
Competition level	2	1.5 *	1 *
DSL availability	100%	95%	75%

* only in areas with DSL coverage, no competition in residual markets

3.2 Technology related inputs

3.2.1 Selected frequency band and system characteristics

We have limited the scope of our study to systems operating on the licensed 3.5 GHz frequency band, due to many of its favorable characteristics. The band is widely available in Europe and supported by all the major WiMAX manufacturers. Unlike in bands above 10 GHz, non-line-of-sight operation is possible. Furthermore, the licensed nature of the band allows higher transmit powers to be used, and interference can be controlled by the operator owning the exclusive rights to the band.

The analyzed system is based on the IEEE 802.16-2004 standard, and utilizes the OFDM physical layer specification. Channel bandwidth of 7 MHz is used and the system utilizes TDD for separating between uplink and downlink transmissions. The spectrum allocation of the operator is assumed to be large enough to allow 6-sector base stations to be deployed without co-channel interference having any significant effect on the capacity.

Simple link budget calculations showing the assumed link gains and losses are shown in Table 3, based on typical values reported by WiMAX equipment manufacturers.

Table 3: System characteristics and link budget calculation

Case	1) Outdoor CPE	2) Indoor CPE
Transmit power	23 dBm	23 dBm
BS antenna gain	16 dBi	16 dBi
CPE antenna gain	18 dBi	6 dBi
Receiver sensitivity	-95 dBm	-95 dBm
System gain	152 dB	140 dB
Fade margin	10 dB	10 dB
Building penetration loss	0 dB	10 dB
Link budget	**142 dB**	**120 dB**

3.2.2 Network architecture and cost components

Regulation in EU countries has resulted to separation of network and service operator businesses of operators. Network operators provide wholesale network services to service operators, which on their part are offering retail services to consumers and businesses. The analysis in this paper is made from network operator business point of view, keeping the focus on the investment levels and network-related operating costs. This means that the revenues are generated from wholesale services sold to service operator(s), and the costs do not include service operator specific elements related to sales and marketing, billing, customer care etc.

In our study, the network operator is assumed to be responsible for building and operating the WiMAX access network and the required transmission links towards a core network access point. Figure 5 shows the network architecture considered to be used for the WiMAX deployment, as well as a respective DSL network architecture.

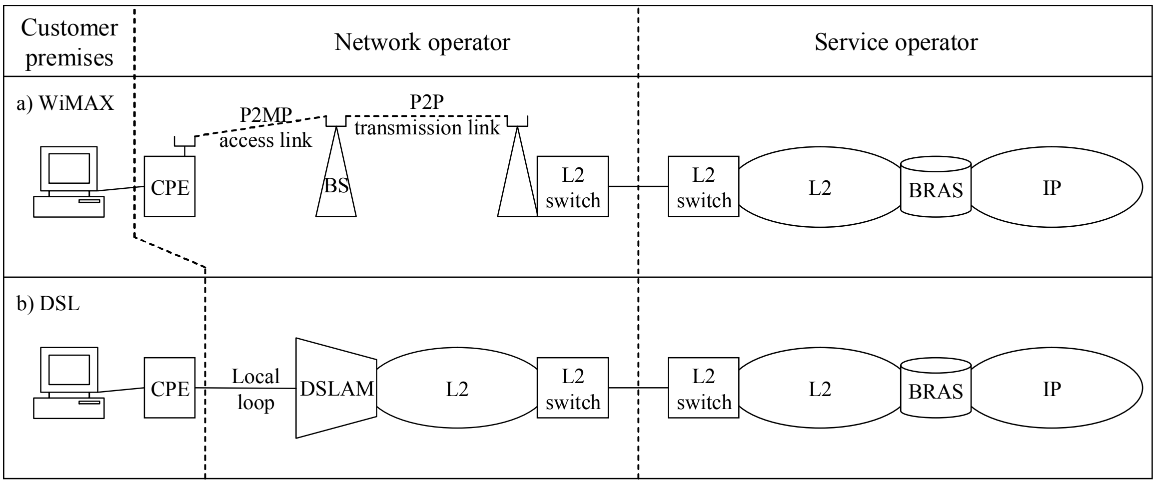


Figure 5: WiMAX network deployment architecture

The major capital expenditure (CAPEX) elements of WiMAX network deployments include the costs of base stations (BS), core point-to-point (P2P) transmission links, and CPEs. In DSL and cable networks, the CPEs are usually owned by either the end-user or the service operator. At the current price levels, however, the WiMAX CPEs cannot be expected to be fully paid for by the end-users, at least in areas where other technological alternatives utilizing low-cost CPEs are available. Therefore, we have assumed the CPEs to be owned by the network operator, and leased out to the end-users at typical DSL/cable modem tariffs. In other words, the network operator is assumed to subsidize the CPEs in order to make the service offering competitive with DSL/cable offerings. For the transmission network part, we have assumed the connections between the base stations and the core network to be built with point-to-point radio links owned by the WiMAX operator.

OPEX elements related to the network roll-out include the maintenance and administration of the network elements, the leasing of equipment space and antenna sites, and installation costs of base stations and CPEs. An important part of OPEX consists of the costs related to the installation of outdoor CPEs, as a technician is required to visit each new subscriber to install and direct the CPE outdoor antennas.

Table 4 lists the CAPEX and OPEX assumptions used in our techno-economic model, together with the expected price evolution over the study period. Price levels of 2006 represent an industry average, and the price evolution is based on the assumption of WiMAX becoming a mass market technology. Price of the OPEX elements is not assumed to change over the study period.

Table 4: CAPEX and OPEX assumptions for WiMAX network deployments

Cost component	Price in 2006	Price evolution
Spectrum license fee (e.g. 8 x 7 MHz)	25.000 €	-
WiMAX 3.5 GHz BS	10.000 €	-15% per year
WiMAX 3.5 GHz BS sector	7.000 €	-15% per year
BS installation cost	5.000 € per BS + $500 per sector	-
BS site rental	1.800 € per BS per year + 1.200 € per sector per year	-
Transmission link equipment (P2P radio link + port in core switch)	25.000 € per BS	-10% per year
P2P radio link site rental	2.400 € per BS per year	-
WiMAX 3.5 GHz indoor CPE	300 €	-20% per year
WiMAX 3.5 GHz outdoor CPE	400 €	-20% per year
Outdoor CPE installation cost	100 € per installation	-
Network equipment administration and maintenance costs	20% of cumulative investments	-

3.2.3 Network dimensioning

In our model, we assume the performance of WiMAX deployments to follow the sector range/capacity curves shown earlier in Figure 3. The maximum sector ranges were calculated assuming the system characteristics shown earlier in Table 3. For Urban areas, the SUI Category A and ECC-33 path loss models were used, whereas the Suburban area sector range was calculated by using the SUI Category B model [10, 11].

Table 5: Range of 3.5 GHz WiMAX cells

Area type	Urban	Suburban	Rural
Cell range, NLOS, indoor CPE	0.56 km	0.73 km	-
Cell range, NLOS, outdoor CPE	2.0 km	2.6 km	-
Cell range, obstructed LOS, outdoor CPE	-	-	10.0 km

For rural areas, the assumed cell range of 10 km was based on an estimate on the density of existing radio masts. Because of the relatively high range requirement, the link conditions have to be sufficiently good to reach the subscribers, i.e. line-of-sight possibly somewhat obstructed by trees etc. We assume that with these cell ranges, all the potential subscribers in the service area will be reached, and existing base station sites and towers can be used for deployment.

The techno-economic model calculates the required number of cells and sectors required to fulfil the coverage and capacity demands of the service area. The model takes into account the capacity/range relationship of the BS sectors, optimizing the rollouts so that the number of BS cells is minimized. In many cases the initial rollout utilizes more robust modulation types for maximum coverage but in the later years, as the subscriber density increases, it becomes more efficient to build new BS cells and utilize the more efficient modulation types for higher capacity.

3.3 Market and service related inputs

In addition to the various technical parameters and assumptions, well-formulated forecasts for service penetration, tariffs, and traffic evolution are also required for our techno-economic analysis. As a basis for the forecasts, we have used broadband statistics available from OECD and the European Commission. Our forecasts and assumptions behind them are discussed in the following sub-sections.

3.3.1 Service penetration and demand

We assume the network deployment to take place in a country with demographics and market situation resembling a European country. As was shown in Figure 1, the broadband service penetration levels differ significantly between the EU countries. Without speculating any further on the reasons behind the differences, we have divided the 25 countries into three groups (Early, Average, and Late) based on the January 2005 broadband penetration levels, and calculated average figures characterising the groups further, as presented in Table 6.

Table 6: Country groups and their characteristics [12, 13]

Group	Early	Average	Late
Countries used in calculating average figures	Netherlands, Denmark, Belgium, Sweden, Finland (5)	France, United Kingdom, Estonia, Austria, Malta, Germany, Portugal, Luxembourg, Spain, Italy (10)	Slovenia, Lithuania, Hungary, Ireland, Poland, Cyprus, Latvia, Czech, Slovakia, Greece (10)
Number of PCs per 100 inhabitants (2002)	47%	32%	19%
Percentage of households having access to the Internet at home (2004)	60%	42%	27%
Broadband access lines per 100 inhabitants			
- July 2002	5.81 %	2.07 %	Not available
- January 2003	7.54 %	2.93 %	Not available
- July 2003	9.20 %	4.02 %	Not available
- January 2004	11.22 %	5.19 %	1.01 %
- July 2004	13.52 %	6.64 %	1.47 %
- January 2005	16.54 %	9.27 %	2.81 %
Percentage of SMEs (10-249 employees) with broadband access (2004)	69%	54%	36%
DSL availability (Jan-05)			
- National	98%	91%	Not available
- Rural areas	91%	69%	Not available

Based on the available data and own assumptions, broadband service penetration forecasts were made for each country group, for both households and SMEs. These forecasts, shown in Figure 6, are assumed to apply for a situation where the broadband availability is 100%. It should be noted that in the beginning of our study period (January 2006), the Early market is already reaching its saturation level, whereas the Late market is just entering the growth phase. The latter situation is often more favorable to a new entrant operator, as the number of new subscribers coming to the market is higher.

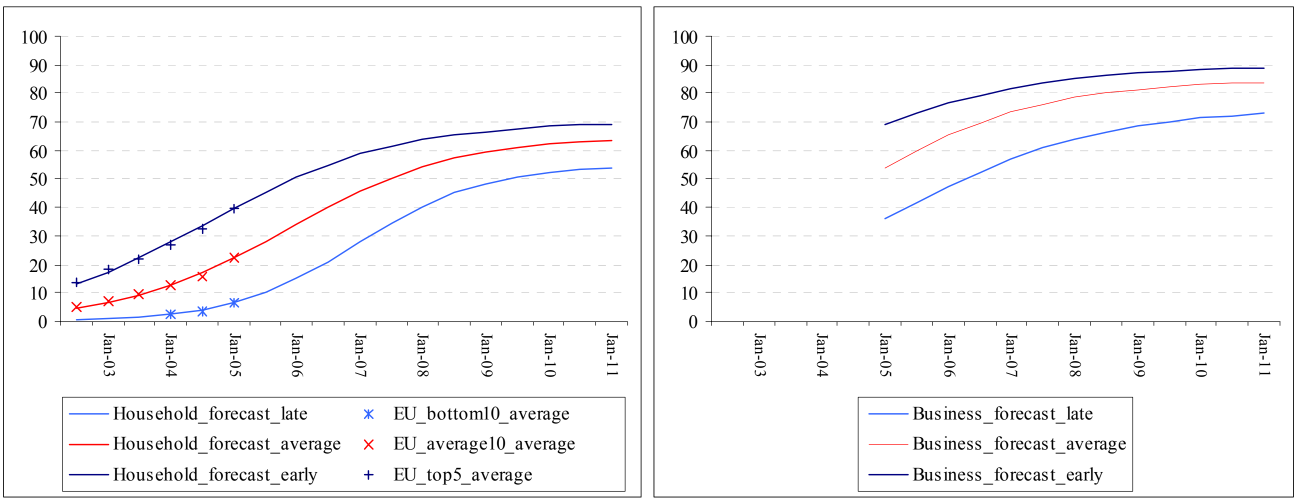


Figure 6: Penetration forecasts for broadband subscriptions

3.3.2 Service characteristics

For the analysis, we consider the network operator's service portfolio to consist of bitstream services of various data rates. Typical service classes enabled by current DSL and cable modem technologies are asymmetric, having data rates of e.g. 512/1024/2048 kbps in the downlink and 128/256/512 kbps in the uplink. Higher downlink data rates of up to 8-12 Mbps are also becoming available.

For simplicity, we have not made separate forecasts for service classes with different data rates. Instead, we forecasted the evolution of the average maximum data rates (uplink + downlink) for both households and SMEs. The annual growth rate is assumed to be 20%, from the initial levels of 1 Mbps for households and 2 Mbps for SMEs.

Overbooking factor (or contention ratio) has an important role in the dimensioning of the broadband access networks. The maximum line capacities of subscribers are not required constantly and the traffic flows of different users can be statistically multiplexed. In the case of DSL, the traffic is multiplexed from the DSLAM onwards, whereas in the case of WiMAX networks multiplexing happens already in the air interface. Typically, overbooking factors of 10-20 are used among operators, although higher and lower values are also possible. Often, the operators do not inform their customers about the overbooking factors in use.

For the purposes of this study, overbooking factors of 20 for the residential users and 4 for business users are assumed throughout the study period. For the network dimensioning purposes, the traffic patterns of residential and business users are assumed to be overlapping so that in the busy hour of residential users 20% of the business traffic is used, and vice versa.

3.3.3 Competition model and WiMAX operator's market share

To forecast the market share evolution of the WiMAX operator, a simple competition model was used, taking into account the broadband service penetration, competition level, and the DSL availability.

In areas with no DSL coverage, the WiMAX operator is assumed to get all of the subscribers desiring broadband services. The WiMAX operator is assumed to satisfy the latent demand of these previously non-served areas during its first year of operation.

In areas with existing DSL/cable coverage, the WiMAX network operator has to compete with the other network operator(s). The WiMAX operator's market share is calculated based on the broadband penetration curve and the competition level parameter that defines how many network operators will be sharing the new subscribers coming to the market. For example, with a competition level of 2 the WiMAX operator will get every third one of the new subscribers.

Churn is assumed to have no effect on the WiMAX operator market share, i.e. the amount of both incoming and outgoing churning subscribers is assumed to be equal.

3.3.4 Service tariffs

The wholesale DSL tariffs of incumbents form a natural reference to be used when assessing the feasibility of WiMAX network deployments. Accordingly, the revenue side of our study is assumed to follow the wholesale DSL tariff levels experienced in the European markets. In other words, we assume the WiMAX network operator to charge the same bitstream tariffs from the service operators that are being charged by the DSL network operators.

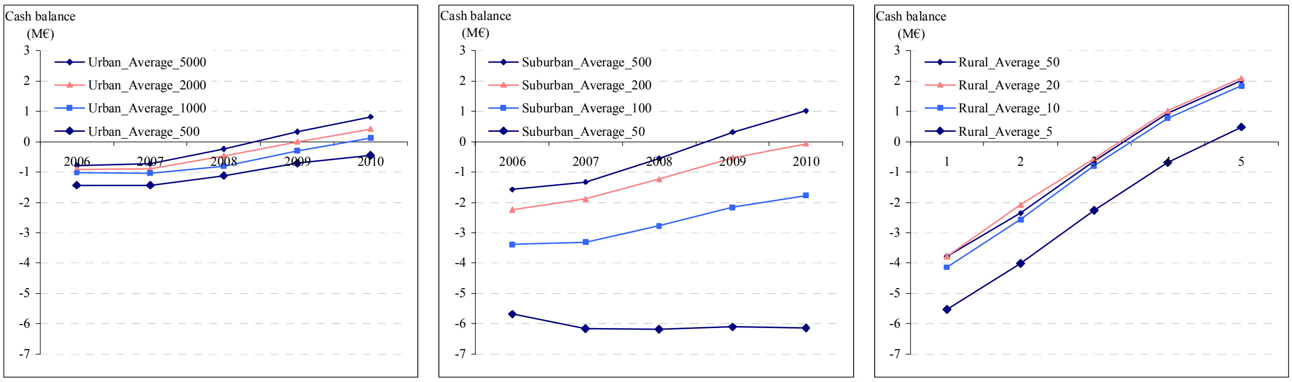
Although the evolution of full ULL and shared access tariffs is regularly measured by e.g. the EU commission, statistical data about the evolution of bitstream tariffs in Europe was not available. Therefore, the tariff forecasts were done in a top-down manner, by first forecasting the retail ARPU evolution and then calculating the bitstream service tariffs as a certain percentage of the retail tariffs.

In June 2004, the average tariffs for subscriptions with 512 kbps, 1 Mbps, and 2 Mbps downlink data rates were 41, 70, and 86 Eur/month (incl. VAT), respectively [14]. Since then, the retail tariffs of different service classes have continued to decrease throughout the Europe, but at the same time the users are migrating to service classes with higher data rates. Therefore, the broadband ARPU (Average Revenue Per User) is not decreasing as fast as the individual service class tariffs. We assume a 15% annual decrease in the retail ARPUs throughout the study period from the 2005 levels of 30 and 200 Eur/month (excl. VAT), for households and businesses, respectively. In order to avoid margin squeeze, the wholesale tariffs have to decrease accordingly. For the purposes of our study, we have assumed the bitstream service tariffs to be 70% of the retail tariffs.

4. Economic results

4.1 Base results

Figure 7 illustrates the base economic results for the different area types with different household densities, and assuming the broadband service penetration to follow the Average-curve. The results show both positive and negative profitability figures for the different area types. In Urban areas, the two most densely populated areas provide positive NPVs and payback in less than 4 years, whereas in Suburban areas only the most dense area turns out positive. In rural areas, the three areas with househould densities in the range of 10-50 1/km^2 give quite similar, positive results, and only the most sparse area is NPV-negative.



Case	NPV (M€)	IRR
Urban_Average_5000	0,534	31,3 %
Urban_Average_2000	0,216	17,8 %
Urban_Average_1000	-0,058	8,1 %
Urban_Average_500	-0,562	-5,5 %

Case	NPV (M€)	IRR
Suburban_Average_500	0,575	23,0 %
Suburban_Average_200	-0,352	3,4 %
Suburban_Average_100	-2,062	-19,1 %
Suburban_Average_50	-6,056	-59,5 %

Case	NPV (M€)	IRR
Rural_Average_50	1,291	24,1 %
Rural_Average_20	1,406	25,7 %
Rural_Average_10	1,072	21,1 %
Rural_Average_5	-0,495	5,9 %

Figure 7: Base economic results for urban, suburban, and rural areas

The effect of subscriber density on the economics of the network deployments is clearly visible in the different area types. Lower household/SME density leads to less efficient use of network equipment and higher initial investments. In dense areas, more efficient modulation schemes can be utilized already with in the early years when the subscriber base is low, improving the subscribers/BS ratio and decreasing the amount of BS sectors and cells required. This is illustrated in Table 7, showing the required numbers of BS sectors and cells for Urban area types with different household/SME densities, as well as the most robust modulation required to be used.

Table 7: Numbers of BS sectors and cells required in the different Urban area types

		2006	2007	2008	2009	2010
Urban_Average_5000	BS cells	2	4	4	5	6
	BS sectors	9	14	22	28	36
	Modulation	QPSK	16-QAM	16-QAM	16-QAM	16-QAM
Urban_Average_2000	BS cells	3	5	5	7	8
	BS sectors	14	19	29	38	48
	Modulation	BPSK	QPSK	QPSK	QPSK	QPSK
Urban_Average_1000	BS cells	5	5	8	9	9
	BS sectors	15	28	43	38	48
	Modulation	BPSK	BPSK	BPSK	QPSK	QPSK
Urban_Average_500	BS cells	10	10	10	10	12
	BS sectors	30	30	43	56	71
	Modulation	BPSK	BPSK	BPSK	BPSK	BPSK

As Table 7 shows, the required investments increase significantly as the household/SME density decreases. To reach the same amount of subscribers in 2010, twice as many BS cells and sectors are required in the sparsest Urban area compared to the densest one, deteriorating the economic feasibility of the deployment. In the earlier years the situation is even worse, as the networks in the sparse areas are clearly coverage-limited.

The effect of differences in the competitive situations in different area types can be seen in the slopes of the cash balance curves in Figure 7. In rural areas, satisfying the needs of the significant residual market requires heavy initial investments, but gives the WiMAX operator a significantly larger subscriber base and annual revenues compared to the urban and suburban areas. In Urban areas, the investments are smaller, but so are the achievable revenue flows. This is illustrated further in Figure 8, showing the investment and OPEX breakdowns for each of the three main area types, together with the annual service revenues.

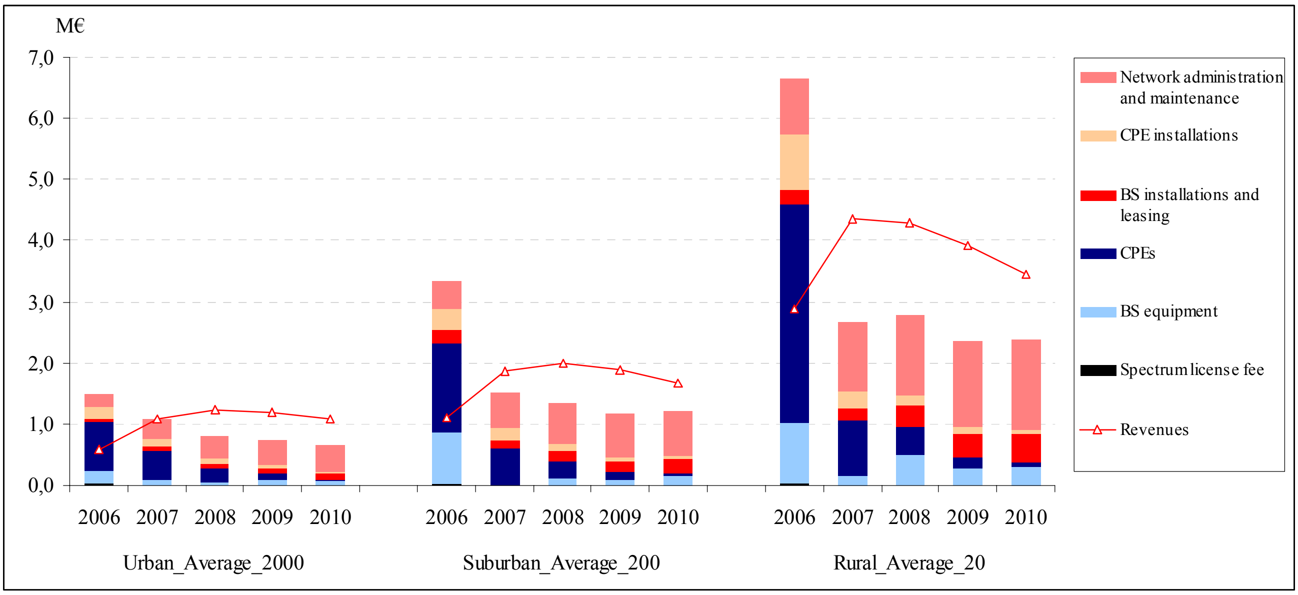
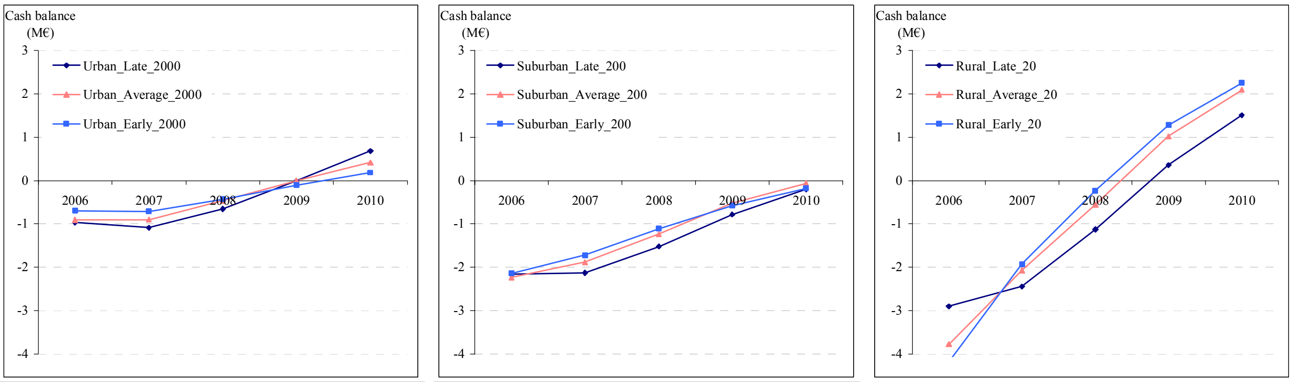


Figure 8: Breakdown of OPEX and CAPEX for three area types

The revenue flows of the operator are declining in the fourth and the fifth year as the markets start to saturate and the ARPU decreases. Investments to CPEs leased out to the subscribers constitute the most significant part of costs in the early years, but overall the relative importance of OPEX compared to CAPEX increases throughout the years. In 2010, OPEX costs constitute about 85% of overall costs in all area types.

4.2 Effect of the service penetration rate

To account for the differences in broadband penetration rates, we specified three different country groups in Chapter 4, called Early, Average, and Late. Figure 9 illustrates the differences in the economic results between these groups.



Case	NPV (M€)	IRR
Urban_Late_2000	0,380	21,1 %
Urban_Average_2000	0,216	17,8 %
Urban_Early_2000	0,024	11,2 %

Case	NPV (M€)	IRR
Suburban_Late_200	-0,420	2,9 %
Suburban_Average_200	-0,352	3,4 %
Suburban_Early_200	-0,499	-0,8 %

Case	NPV (M€)	IRR
Rural_Late_20	1,001	21,9 %
Rural_Average_20	1,406	25,7 %
Rural_Early_20	1,466	26,2 %

Figure 9: Results for selected urban, suburban, and rural area types assuming different country groups

The profitability figures for Urban areas support the hypothesis of Late markets being more profitable for new entrant operators. In the Rural areas, however, the order is different. This results from the partial unavailability of DSL that has created a higher latent demand in the Early markets compared to the Late markets. In the Early market, the WiMAX operator captures a higher share of the market in its first year of operation, giving rise to revenue flows outweighing the higher initial investments. In Suburban areas, the effect of the residual market is less significant, and the results are more ambiguous.

4.3 Indoor vs. outdoor CPEs

The investment breakdown of Figure x pointed out the high amount of outdoor CPEs required to minimize the number of BS cells and sectors. Even in the most densely populated scenario, the share of indoor CPEs out of all is only 19% in 2010. Outdoor CPEs are more expensive than indoor CPEs and bear an extra installation cost. Furthermore, special permissions for installing outdoor antennas may have to be acquired from the property owners, causing extra burden to operators and potential subscribers.

Thus, indoor CPEs are in many ways preferable to outdoor CPEs. The fallback, however, is the significantly lower link range resulting from lower gain omni-directional antenna and loss in signal strength when penetrating walls and windows of buildings. According to results from our model, network deployments dimensioned exclusively for indoor CPEs are profitable only in the most dense Urban areas (5000 households / km^2), and even then the profitability is lower than in deployments mixing indoor and outdoor CPEs.

4.4 Sensitivity analyses

To cope with the uncertainty inherent in many of our assumptions, sensitivity analyses were made on the key input parameters to our model. The parameters included in the sensitivity analysis are BS sector capacity, BS sector range, BS price, CPE price, and the service ARPU level. For each parameter, 50% deviations from the base assumptions were defined as the upper and lower limits for the sensitivity analysis. The parameters were analyzed one-by-one, changing their values between the minimum and maximum and plotting the respective NPV figures into sensitivity graphs.

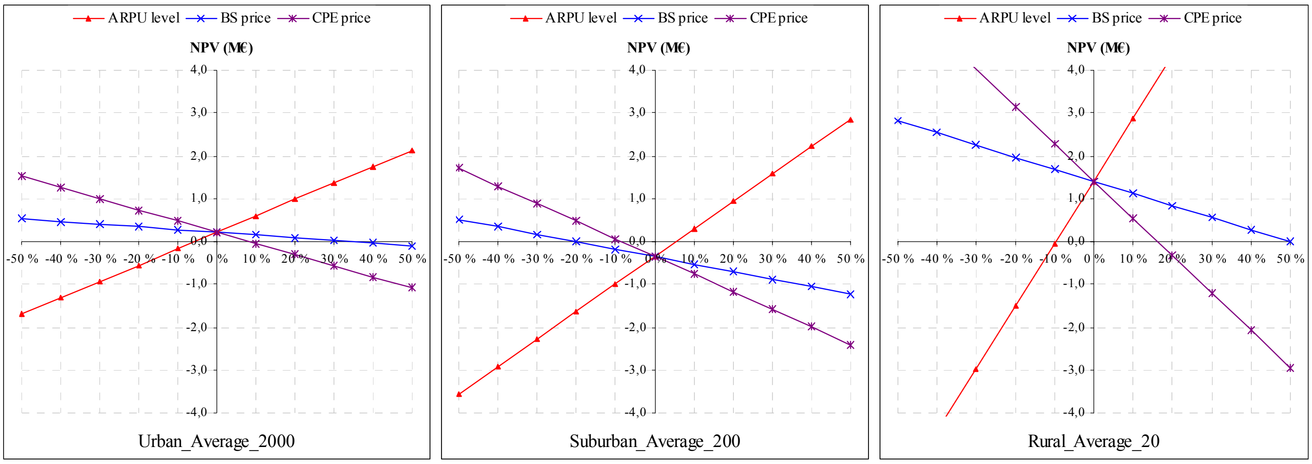


Figure 10: NPV sensitivity to changes in ARPU level, BS price, and CPE price assumptions

The NPV sensitivity to ARPU level, BS price, and CPE price assumptions is rather similar in all the area types. Differences lie in the base NPV levels and in the slopes of the sensitivity curves, resulting from the different scale of the projects regarding both investments and reached subscriber amounts. The graph (Figure 10) shows that the project NPVs are significantly more sensitive to changes in the CPE prices than in the BS prices, which is natural as CPEs constitute a lerger share of the operator's investments. Changes in the ARPU level (or alternatively in the network operator's share of ARPU) are, however, having the largest impact on the profitability of WiMAX deployments.

Interestingly, sensitivity analysis with regard to WiMAX BS sector capacity and range gives quite different kinds of results for the different area types, as shown in Figure 11.

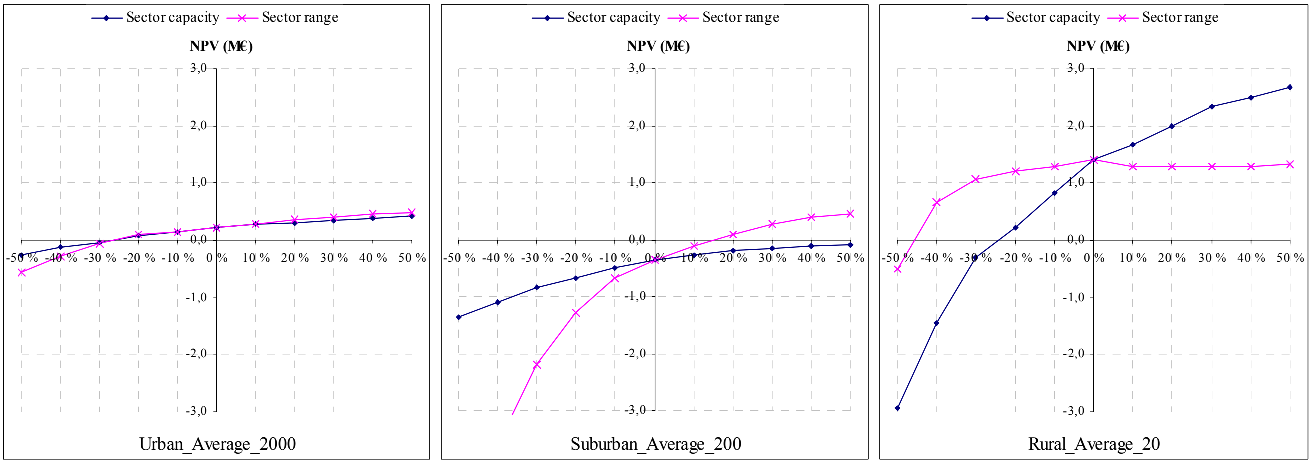


Figure 11: NPV sensitivity to changes in sector capacity and range assumptions

The NPV sensitivity to sector range is similar in the Urban and Suburban areas, growing slowly when the range is increased, and falling more rapidly when the range is decreased below the base assumption. This shows that as the BS cells become capacity- rather than coverage limited, the importance of the cell range diminishes. The situation is even clearer in the rural area case, where the project NPV is actually indifferent to changes in the sector range after a certain point (about 8 km in this particular case). According to the figure, the rural area NPV stays positive until the cell range is decreased to 5.4 km. In practice, however, the rural area deployment relies on existing radio towers, and the range demands are dictated by the density of them.

The importance of BS sector capacity varies between area types. The Suburban area results are interesting in that the project NPV is quit indifferent to increases in the sector capacity, suggesting that the network deployment is still coverage-limited with the base range assumptions. This is backed up by the fact that BPSK modulation is used throughout the study period in this area scenario. In rural areas, the base network deployment is capacity-limited, and the NPV is very sensitive to changes in the sector capacity.

5 Summary and conclusions

WiMAX-based fixed wireless access networks have been proposed to induce facilities-based competition in the broadband access market, as an alternative technology to DSL and cable networks. In this study, we have analyzed the viability of WiMAX network deployments for providing fixed broadband access services to households and businesses in various area types and market conditions.

The results of the analysis show that WiMAX network deployments can be profitable in dense urban areas as well as in rural areas where the availability of other alternatives is limited. Low profitability can be expected in urban and suburban areas with medium population densities and high availability of other access network alternatives.

The results of our study are also useful in clarifying the performance level of 3.5 GHz WiMAX systems, often exaggerated by the industry players. The tradeoff between coverage and capacity is evident in our case scenarios; in some area types the networks are coverage-limited, whereas in others the sector/cell capacity defines the required investments. Generally, coverage-limited network deployments are less profitable. The performance of WiMAX systems appears to be suitable for the broadband traffic demands of today, but the emergence of services requiring data rates above 2-4 Mbps per subscriber will be problematic for the WiMAX operators.

Sensitivity analyses reveal that the most critical success factors for WiMAX networks are the CPE price and broadband tariff levels. Minimizing the total cost of outdoor CPEs, including the equipment and installation costs, is vital when pursuing a profitable business case, as all-indoor CPE deployments are generally non-profitable due to excessively high initial investments.

Future work includes expanding the techno-economic model to analyze WiMAX evolution paths from fixed broadband access to portable and mobile applications. The IEEE 802.16 working group is currently working on an extension to the standard, aiming to make the technology suitable for mobile applications. The standard is expected to be finalized in late 2005, and it will take some time before compliant products become available. In the meantime, the first WiMAX systems will have to prove their competitiveness against DSL and cable modem systems. Failure in the fixed broadband market would probably have implications also on the prospects of WiMAX in the future markets.

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