Project Number:	FP6-IST-507554
Project Title:	BROADBAND in Europe for All: A Multidisciplinary Approach

CEC Deliverable Number:	FP6-IST-507554/COM/R/Pub/D2.4-3.4
Contractual Date of Deliverable to the IS DG:	N/A
Actual Date of Delivery to the IS DG:	10/05/2006
Title of Deliverable:	Techno-economic study
Workpackage contributing to the Deliverable:	WP2: Multi-technological analysis WP3: Techno-economic, socio-economic and policy studies
Nature of the Deliverable	R – Report

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Abstract:
A techno-economic model for analysing and comparing broadband deployment strategies has been established. The resulting simulation model can compare Capital Expenditure (CAPEX) of dominating broadband technologies in different types of demographic areas. The study reveals the competitiveness and applicability of different access technologies in the future broadband market as well as providing sensitivity analysis of the most influential factors controlling market development.

Keyword list:
Broadband for All, techno-economic analysis, multi-technological, multi-disciplinary analysis, socio-economic

Disclaimer

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Executive Summary

Several technical solutions exist for provision of broadband to customers in different types of demographic areas. Research indicates that the future market will be characterised by different coexisting technologies, the choice of which is determined by technological capabilities as well as economic factors.

The BREAD project has on basis of results from other projects in the EU Framework Program 6 analysed technological alternatives, future trends, and status of broadband initiatives. Results from following European techno-economic projects have been applied in the modelling work: BREAD, TONIC, ECOSYS, BROADWAN and FAN. For the purpose of this report techno-economic methods are used to analyse and compare deployment scenarios for five of the most widely used technological alternatives. A simulation model has been developed to examine the effect of influential factors, such as transmission speed and level of existing infrastructure, in providing broadband connectivity in urban, suburban and rural areas. For those technologies building on use of existing infrastructures calculations are made both for a two different scenarios: Upgrade of existing infrastructures and greenfield.

The strength of this study in comparison to many of the detailed feasibility studies of broadband deployment is the general overview and comparison of the deployment cost for different technologies and deployment scenarios. The goal of this study is therefore to provide rough estimates that indicate competitive strengths and weaknesses of technologies, rather than to aid in execution. In the absence of reliable data on operational cost from operators, the model only calculates the capital expenditure (CAPEX).

The study reveals and verifies the current trend of DSL & Cable dominance in the urban market segment, where existing infrastructure facilitates inexpensive equipment upgrades. There is a fundamental trade-off between reach and capacity in most access technologies and extending the coverage of xDSL technology to provide higher capacities for less populated areas will be expensive and the study reveals a clear window of opportunity for wireless technologies in rural and suburban areas.

Future service scenarios are expected to demand increasing transmission capabilities and with the introduction of triple-play services, substantial new infrastructure investment is needed. For these scenarios, comparison of deployment cost becomes more subjective. While wireless and copper/coaxial based infrastructures require less capital investment it is unrealistic since fibre based infrastructures provide a more future safe solution. For these new infrastructures, optimisation of network structures is critical and merely replacing copper with fibre would result in substantially higher cost than otherwise required.

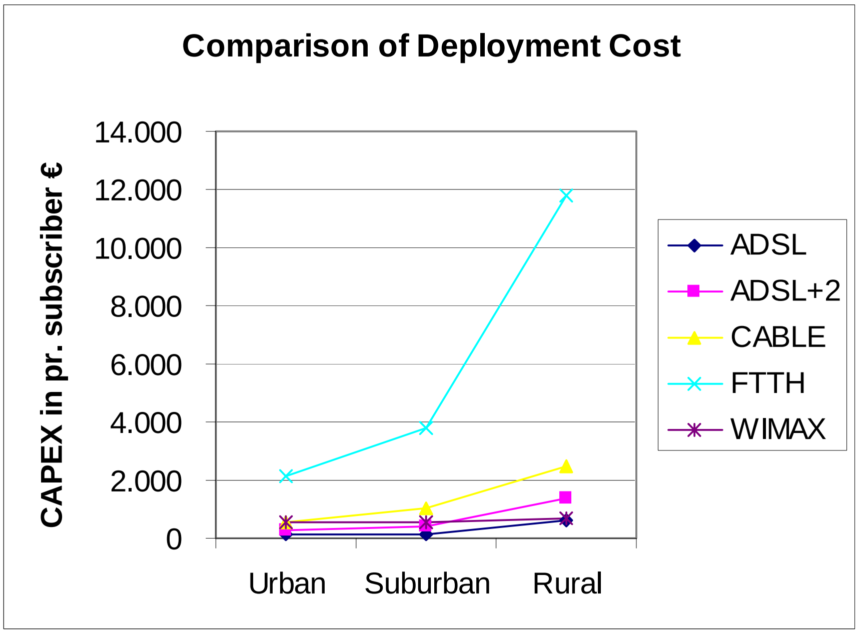


Figure 1: Comparison of technologies for service profile 3

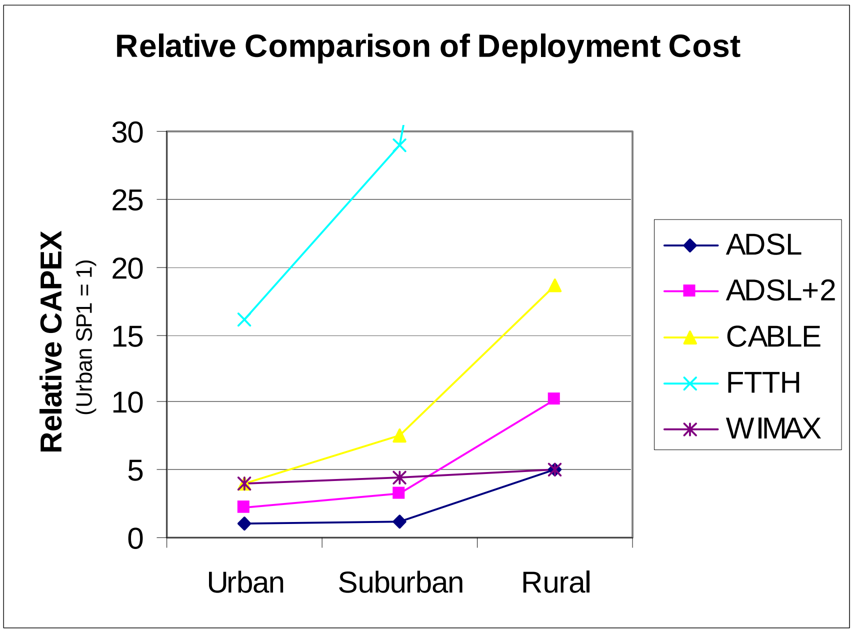


Figure 2: Relative CAPEX comparison of all technologies for service profile 3

The cost study examines CAPEX cost structures involved in deployment of DSL, HFC, FTTH and WiMAX. The study reveals difference in cost structures between technologies and their ability to handle varying services and transmission speeds. The study reveals that currently all technologies are competitive in the urban settings, with the exception of FTTH, which is only feasible if other groundwork is carried out at the same time.

For the suburban and rural areas, there will be a gap between those living in the vicinity of existing telecommunications infrastructure, such as PSTN, and those living further away.

Although detached DSLAMs have the possibility of decreasing this gap for DSL, the additional cost of establishing a backbone fibre connection to these aggregation points results in a ten times higher cost. For these users, WIMAX provides and excellent short-term solution for providing internet connectivity. The drawback of WiMAX is the temporary nature due to expensive transmission pr. bit and thus high upgrade costs for increased throughput.

In all areas, FTTH provides an expensive but future-proof solution. Our analysis shows that roughly 60% of the CAPEX for FTTH in all scenarios is due to civil work, ducts, and cables. In rural and suburban areas, the result of this could be smaller deployment zones where citizens reduce the cost by participating in ground work, and / or local governments reduce the cost by granting connectivity to established backbone networks.

Of the technologies studied, DSL and cable modem (HFC) are currently by far the most dominating broadband access technologies worldwide in terms of volume. These two technologies are now quite mature – a fact that is reflected in the price evolution of equipment during the past few years. Given a similar evolution for fibre and wireless equipment, the dominant cost component, Customer Premises Equipment, will greatly improve competitiveness in urban areas, and similarly advanced digging methods have the potentials of greatly reducing the dominant cost of civil work of fibre in rural areas.

1. Introduction

1.1 Objectives

The objective of this study is to create an up-dated techno-economic model for comparing different ways of deploying broadband communication networks and services. The resulting simulation model Capital Expenditure (CAPEX) of different implementation strategies comprising of predefined access technologies, service profiles, and geographical scenarios. More specifically the model shall include the following components (definitions and term descriptions follow later in the report):

Access Technologies:

- ADSL
- ADSL2+
- HFC Cable modem
- FTTH
- WiMax

Service Profiles:

- S1: Slow Internet Browsing
- S2: Fast Internet Browsing
- S3: Multimedia
- S4: Interactive Multimedia

Geographical Profiles:

- Urban
- Suburban
- Rural

Scenarios:

- Greenfield
- Existing Infrastructure Upgrade

1.2 Methodology and Relation to other Research Projects

The model developed in this report draws on the work carried out in various other research projects. The terminology, methodology, and theoretical framework are influenced by European techno-economic research projects: TONIC, TETRA, ECOSYS and BROADWAN while the infrastructure and technology aspects draw from BREAD, FAN and BROADWAN. More specifically the relationship to these projects is as follows:

BREAD

Broadband in Europe for All: a multi-disciplinary approach aims at developing a roadmap for the deployment of broadband and realisation of the 'broadband for all' concept within Europe. This report relies on the access and backbone network overview provided in deliverable 2 [2]

TONIC

IST-2000-25172 TONIC (TechnO-EcoNomICs of IP optimised networks and services) concentrates on techno-economic evaluation of new communication networks and services. Following up on older projects, TONIC was carried out in 1998-2002 and provides the foundation of most theoretical and methodological work on techno-economic studies. This project therefore provided a starting point for development of the simulation model [11].

ECOSYS

An ongoing research project on the techno-economics of integrated communication systems and services. The most interesting part of the ECOSYS project for this study is the advancement and evolution of the theoretical and methodological framework developed for techno-economic analysis of telecommunications networks in the TONIC project. [5]

BROADWAN

The goal of the "Broadband services for everyone over fixed wireless access networks" is to investigate how wireless networks can be used to provide true broadband services. The most interesting aspects of the BROADWAN project for this study is the analysis of market potential and deployment scenarios and future development of wireless access technologies. Additionally, the project has developed a simulation model for deployment cost based on methods developed in the TONIC project. [3]

FAN

EURESCOM P1117-FAN evaluates the technical specifications of future access networks, the impact of IP and infrastructure architectures. For this report it was used to reinforce the infrastructure and access technology selection. [6] [7]

1.3 Model Structure and Functionality

The overall model structure is based on dividing the network into two segments: Access Segment and Backbone Segment. The Access Segment covers the so called "first mile" from user premises to an aggregation node in the respective zone. This part is characterized by a diversity of transmission media (copper, fibre, cable, radio), and topologies (star, tree). The Backbone Segment is an aggregation network connecting all Aggregation Nodes to Service Nodes. This part is characterized by one transmission media, optical fibre connections but a diversity of topologies (star, tree, ring). See Figure 3.

Layer 1: Access Segment *Layer 2: Backbone Segment*

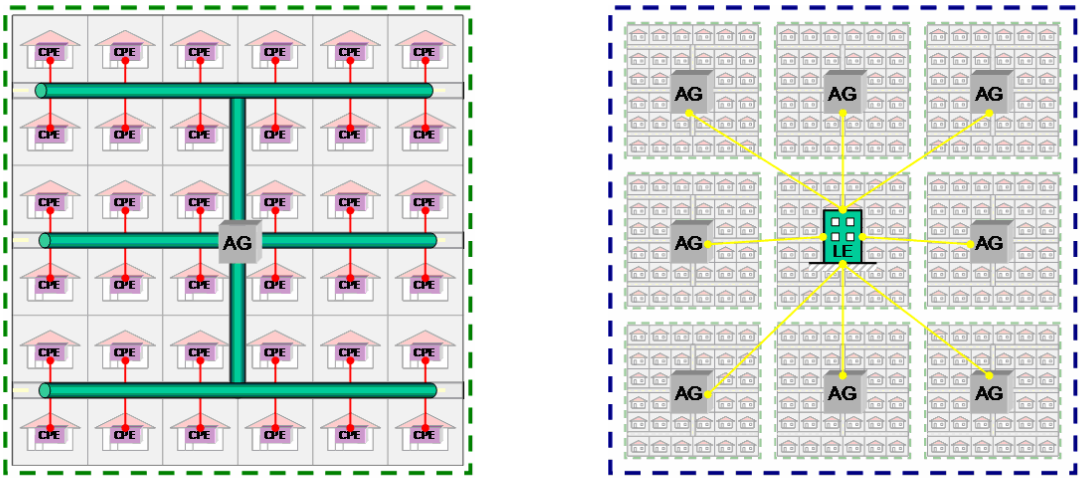


Figure 3: Two segment, access and backbone infrastructure model

Configuration parameters for the model can be classified into Scenario Parameters (Geo-graphic, Population Distribution, Existing Infrastructure, and Available Service) and Technology Parameters (Access Technology and topology, Backbone Technology and topology etc.).

Together, geographic information and population distribution determine to a large extent the investment cost of access networks. The most relevant parameters are number of buildings/customers and the distance between them. The model can either take note of already existing infrastructure or assume "Greenfield" deployment.

1.4. Model Implementation

The model is implemented as an Excel spreadsheet solution with a Graphical User Interface (GUI) in Visual Basic for Applications according to the following system architecture.

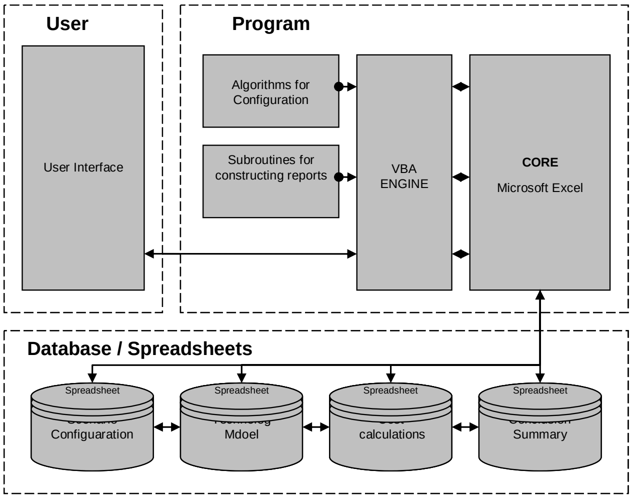


Figure 1: System Architecture of the model [10]

The model runs as a standalone spreadsheet in Microsoft Excel 2000/XP/2003. The Excel core runs in the background performing calculations on the data stored in spreadsheets while users interact with the model through a graphical user interface (GUI) developed as a Visual Basic User From. Each access technology is implemented through a separate technology and cost model spreadsheets while scenario configuration is common to a single Scenario Model Spreadsheet. Apart from interrelationship between spreadsheets some standard configuration algorithms are stored in VBA and executed upon demand.

1.4 Executing and Using the ModelWired Standards

The GUI is executed automatically when the spreadsheet is opened through the Visual Basic for Application (VBA).

Figure 2: Graphical User Interface (GUI)

2. Techno-Economic Framework

The techno-economic framework used consists of the following components:

- Geometric Model:
- Geographic Model
- Service Model
- Network dimensioning rules and cost
- Cost models for investment (CAPEX)

2.1 Geometric Model

Geometric models provide the basis for calculating the required amount of trenches, ducts and cables. This task can be done with a varying level of detail, taking as input geographical description, population size and distribution, topology, and level of existing infrastructure. In this report we assume a rectangular geographic area divided among homogeneously distributed buildings. The area is divided into access zones, in all of which an equal number of buildings is connected through vertical and horizontal trenches to the nearest Aggregation Node (AN). The topology in which NTs are connected to an AN, is determined by the applied access technology and can be star, ring, or bus. In the same manner, all aggregation nodes connect to a centralised Service Node (SN) using star, ring, or bus. See Figure 3.

2.2 Geographic Description

The model has three geographic scenarios: urban, suburban and rural. Each of these can be configured through configuration parameters: Households, Population Density, and Households pr. Building. Unfortunately, there is no consistent definition across European counties of urban, suburban, and rural areas. Each National Statistical Institute uses a specific coding, even if their definitions are often very close. [3, p. 30]. For this project, we have gathered statistical information for Scandinavia, as described in Table 1.

For a neutral demonstration of the model calculations, we will in the remainder of this report depict a simulation of 100.000 households in three fictional geographical scenarios and simulate penetration rates of 25% (see Figure 6). A comparison reveals a mismatch where the three scenarios used are more densely populated than corresponding values from Scandinavia. This is intended and done to provide conformity to earlier techno-economic studies.

Geographic Description

	Urban	*Suburban*	*Rural*
Households [units]	100.000	100.000	100.000
Population Density [Households/Km^2]	10.000	1.000	100
Households pr. building	16	4	2
Buildings	6.250	25.000	50.000
Deployment Area [Km2]	10	100	1.000

Market Potential

	Urban	*Suburban*	*Rural*
Market Uptake	25%	25%	25%
Customers	25.000	25.000	25.000

Configuration Parameters
x Calculated Parameters

Figure 3: Geographic configuration parameters used in the simulation and 25% uptake

	Land, sq.km.	Water, sq.km.	Total areal, sq.km.	Population 2002	Inhabitants per sq.km. of land	Percent of population
DENMARK	**42.393**	**700**	**43.093**	**5.368.354**	**127**	**85%**
Copenhagen Region	2.757	106	2.862	1.814.564	634	34%
Copenhagen	85	3	88	500.531	5.688	9%
Aalborg Region	6.125	48	6.173	495.548	80	9%
Aalborg	554	6	560	162.264	290	3%
Odense Region	3.472	14	3.486	472.504	136	9%
Odense	304	0	304	183.628	604	3%
Århus Region	4.493	68	4.561	644.666	141	12%
Århus	466	3	469	288.837	616	5%
FINLAND	**304.592**	**33.553**	**338.145**	**5.194.901**	15	**65%**
Helsinki Region	2.968	123	3.091	1.213.743	393	23%
Helsinki	184	1	185	559.718	3.026	11%
Tampere Region	1.719	485	2.204	298.655	136	6%
Tampere	523	168	691	197.774	286	4%
Oulu Region	3.803	59	3.862	192.974	50	4%
Oulu	323	11	334	123.274	369	2%
Turku Region	1.717	8	1.725	292.145	169	6%
Turku	243	2	246	173.686	706	3%
ICELAND	**100.243**	**2.757**	**103.000**	**286.575**	3	**92%**
Reykjavik Region	1.094	6	1.100	178.301	162	62%
Reykjavik	268	2	270	112.411	416	39%
NORWAY	**306.252**	**17.506**	**323.758**	**4.524.066**	14	**74%**
Oslo Region	5.014	357	5.371	989.914	184	22%
Oslo	427	27	454	512.589	1.129	11%
Bergen Region	3.248	137	3.384	338.611	100	7%
Bergen	445	21	465	233.291	502	5%
Stavanger Region	1.784	125	1.907	257.096	135	6%
Stavanger	66	4	70	109.710	1.567	2%
Trondheim Region	2.429	113	2.542	205.998	81	5%
Trondheim	321	21	342	151.408	443	3%
SWEDEN	**410.934**	**39.035**	**449.969**	**8.909.128**	20	**83%**
Stockholm Region	3.455	1.445	4.900	1.674.380	342	19%
Stockholm	188	28	216	754.948	3.495	8%
Gothenburg Region	2.930	157	3.087	803.941	260	9%
Gothenburg	451	14	465	471.267	1.013	5%
Malmö Region	1.622	27	1.649	527.633	320	6%
Malmö	154	1	155	262.397	1.693	3%

Table 1: Statistical Information on Scandinavia[1]

2.3 Service Profiles

Service profiles vary in their upstream and downstream bit-rates in both access and backbone segments. Backbone bandwidth requirements are calculated by dividing access segment traffic by a multiplex ratio which determines how easily the traffic can be shared. This value is generally lower for traditional web browsing than for multimedia services and peer-to-peer traffic. In this report we consider four service profiles which can in some respect be seen as consecutive future steps in user demand.

- SP1 - Slow Internet Browsing
- SP2 - Fast Internet Browsing
- SP3 - Multimedia
- SP4 - Interactive Multimedia

[1] Source: Statistical Finland (http://pxweb2.stat.fi/Dialog/Saveshow.asp)

For most technologies, there is not a direct cost relationship with bandwidth in the access network, although in reality operators might use different bandwidth offers for price differentiation. The importance of the service profiles stems from their influence on network infrastructure design and in most cases the maximum allowable cable length in addition to controlling the resources in the backbone network.

Service Profiles	Access Network			Backbone Network	
	Upstream	*Downstream*	*Ratio*	*Upstream*	*Downstream*
S1: Slow Internet Browsing [Mbps]	0,2	2,0	30	0,007	0,1
S2: Fast Internet Browsing [Mbps]	0,8	8,0	15	0,053	0,5
S3: Multimedia [Mbps]	2,0	20,0	15	0,1	1,3
S4: Interactive Multimedia [Mbps]	20,0	20,0	5	4,0	4,0
Selected profile for simulation	0,20	2,00	1	0,01	0,07

Figure 4: Service Profile specifications

2.4 Network dimensioning

Although different in implementation we assume that all access technologies share the same basic network dimensioning. We use the maximum cable/reach distance to divide the total geographic area into equally sized rectangular access zones (see Figure 8). Each access zone is again divided into units where each unit hosts one building. Each building has a certain number of households, each of which connects to the nearest access node (AN).

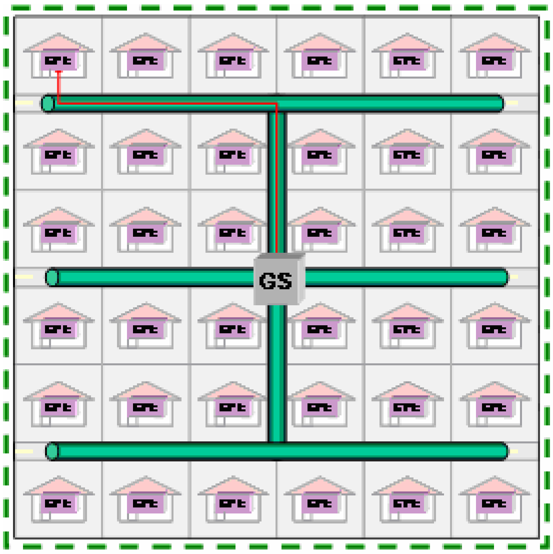


Figure 5: Maximum cable/reach distance controls the size of an access zone

2.4.1 Geometric Terminology

The geometric model used is based on dividing areas into rectangular units. Each access zone contains *n* number of units, in a total area of unit breadth and width a = √n.

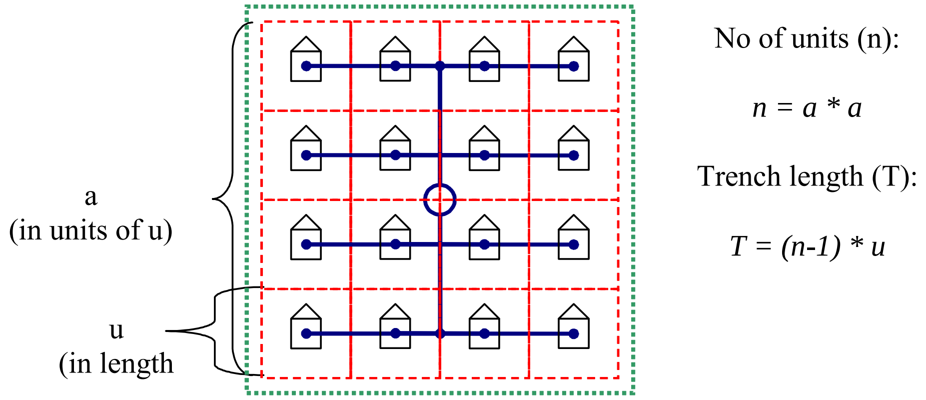


Figure 6: Geometric Model and calculations for trench length

2.4.2 Trenches and Ducts

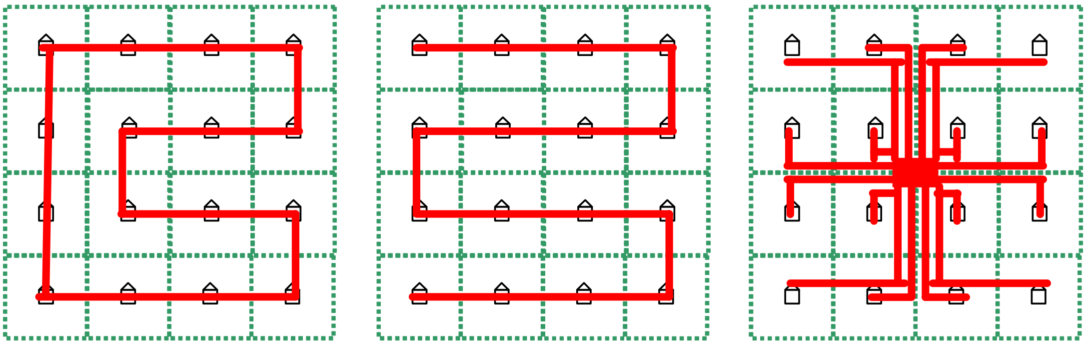
Trench length represents the civil work required for digging down ducts and cables. A duct or sub-duct is a pipe, tube or conduit through which cables or wires are passed. These ducts protect the cables and facilitate the installation of more cables at a later stage without re-opening the pavement or road surface. In the model we make the assumption that a single duct carries all passing cables in shared trenches (i.e. there are never parallel ducts in a single trench). The length of ducts therefore becomes equal to that of the required trenches. Given bus topology, the general formula for duct and trench length in the geometric model used in this report becomes:

Trench and duct lengths = (units-1) * unit_length

2.4.3 Cable lengths

The required length of cables is determined by the topology used. This model can calculate cable and duct length for star, ring and bus topology in both access and backbone network segments. The generalised formulas for the geometric model used are displayed in Figure 10. As we can see there is little difference in the required length between ring and bus, while the required length for star topology increases exponentially with the number of units.

RING	BUS	STAR



Cable length (C^{ring}):	Cable length (C^{bus}):	Cable length (C^{star}):
$C^{ring} = n * u$	$C^{bus} = (n-1) * u$	C^{star} = (n)^(3/2))/2

* where n is the number of units, u is the length of a unit

Figure 7: Geometric Model and calculations for cable lengths (for terminology see Figure 6)

2.4.4 Equipment

The required equipment varies from technology to technology. Furthermore, the price and capacity of equipment is different between vendors and even between customers for the same equipment. An accepted trend in equipment cost is related to the maturity of a technology, where in theory production prices drop with mass production, economics of scale and vendor competition. As an example of this, [3, p. 2] and [8, p. 12] estimates that the cost of ADSL Customer Premises Equipment (CPE) and line cards has dropped down to around ¼ of the 2000-level, and that similar trends are expected for other emerging technologies. While many other techno-economic models that evaluate the economic feasibility of deployment scenarios incorporate cost development over a period of time, this project is more focused on a static cost comparison of different technologies. The approach is therefore to investigate the current status and at the end of the report to perform a sensitivity analysis to investigate the effect of development, rather than predict it.

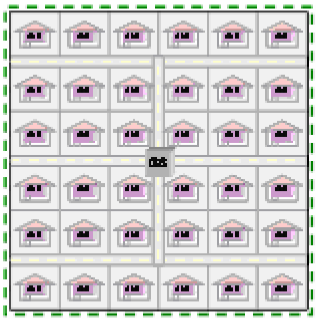
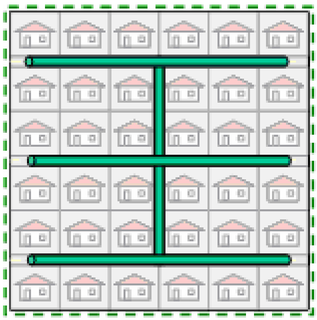
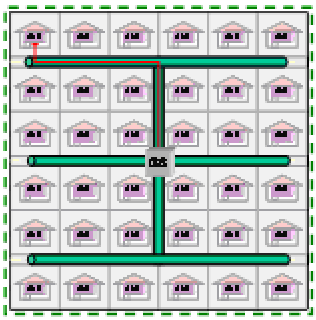
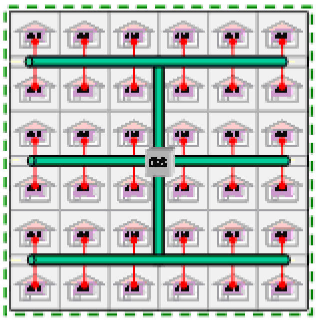
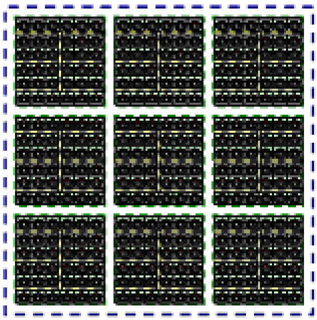
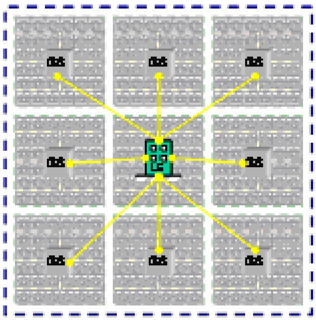
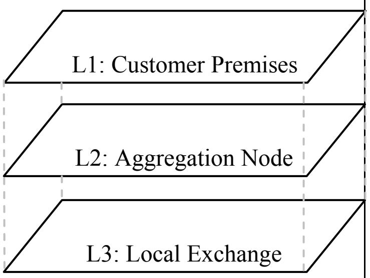
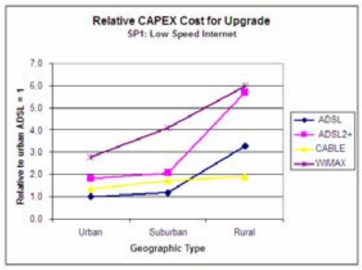
2.4.5 Calculating Total Capital Expenditure

The Capital Expenditure of each scenario/technology is summed up in a special Expense Sheet. Cost components are grouped into access segment and backbone segment. Total CAPEX, is then broken down to: i) per. customer, and ii) per passed home. Simulation comparison between different technologies / deployment scenarios is summed in the "Conclusions" sheet. The comparison can be depicted in € or prices relative to urban ADSL, service profile 1.

2.4.6 Summary of Methodology

Below is a visual summary of the methodology used:

1. Geography	2. Access Segment	3. Ducts and trenches

 Each access zone consists of a rectangular area with evenly distributed buildings	 Each building contains a number of apartments and each access zone one street cabinet	 Ducts and trenches run vertically and horizontally, interconnecting each building
4. Dimensioning  Maximum cable limits access zone size	5. Cabling  Buildings connect through star, bus, or ring topology	6. Backbone Segment  Total area consists of several access zones
7. Backbone Segment  Access zones connect to one Central office	8. Cost Components  The model calculates and makes a list over the required equipment at all layers	9. Compare scenarios  Deployment cost of each technology / deployment scenario is summed up visually

3. Cost analysis for DSL Networks

3.1 General Description

A Digital Subscriber Line (DSL) network can be described by the following figure:

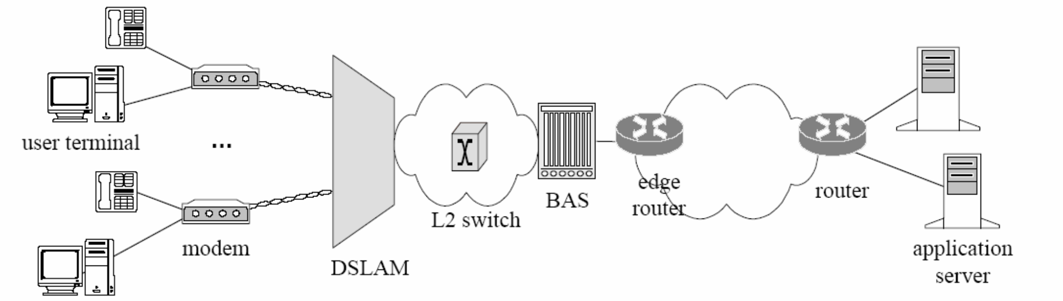


Figure 8: DSL network overview [2]

As described in [2], DSL technology reuses the copper twisted pair infrastructure to offer data transmission services. This is done by using the frequency range above PSTN for high speed data transmissions. The main strength of DSL in a techno-economic sense is the considerably lower initial investment compared to technologies that require a new physical infrastructure. Additionally, due to the star based topology of the physical infrastructure on which DSL networks are built, each customer gets a dedicated connection to the aggregation node in the DSLAM, compared to a shared connection in tree based topologies such as Hybrid Fibre Coaxial (HFC) networks. The main weakness stems from the transmission limitations arising from the same reuse of an existing infrastructure that was designed and dimensioned for analogue telephone transmission and not high speed data transmissions.

3.2 Technical Description

There are several variants of the DSL technology, such as Asymmetric (ADSL), Symmetric (SDSL), Very high bit rate (VDSL). Each of these variants has distinctive characteristics but to generalise, the decisive properties are bandwidth, range, and symmetry. These three parameters are to a large extent internally related, where high speed or symmetry limit range, and vice versa. The required bandwidth of the services offered over a DSL network therefore limits the maximum copper cable distances, increasing the number of access nodes, and consequently increasing the cost.

For the purpose of this study we have developed a VBA function Range (transmission_rate, technology), which calculates the maximum allowable cable length for ADSL and ADSL2+ for a given maximum transmission rate in the model. The output of the function in plotted in Figure 12.

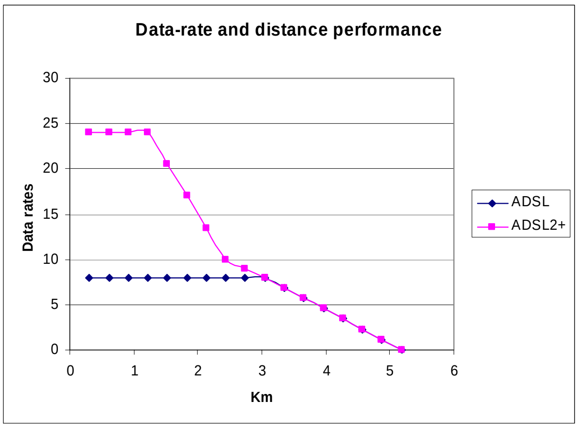


Figure 9: Data-rate and distance performance of DSL

3.3 Scenario Description

In this report we consider the deployment of ADSL and ADSL2+ in an upgrade scenario where we assume an existing infrastructure. We are interested in examining how the deployment cost is affected by changes in service offering in the three geographic scenarios. In reality, the deployment cost and technical implementation is determined by characteristics of the existing infrastructure and the type of operator, and not only the services offered. This means that the cost of providing 2 and 8 Mb/s transmission is basically the same as long as the cable length to the user can support the transmission rate.

In this study we have to make the assumption that the maximum copper length can support the transmission rate of each simulation, i.e. that the copper length is within the required value of Error! Reference source not found.. This assumption is taken to give a comparison of different deployment situations rather than different alternatives in the same area.

For the aggregation/backbone segment we assume that a new fibre network needs to be established, resulting in expensive civil work. In reality the accuracy of this assumption again depends on the level of existing infrastructure in addition to the type of operator. A concrete example of the applicability of the scenario is included within each technology section.

3.4 Main Cost Components

For establishing a DSL network the main cost elements are:

- Customer Premises Equipment (modem in Error! Reference source not found.)
- Local Loop (access/operational fee for the copper twisted pair)
- Digital Subscriber Line Access Multiplexer (DSLAM in Error! Reference source not found.)
- Aggregation Network (L2 switch in Error! Reference source not found.)
- Broadband Remote Access Server (BAS in Error! Reference source not found.)
- Management System

Since all cost elements are hardware and software components, the operational cost (OPEX) can be considered proportional to the CAPEX, roughly estimated to 20%. For a detailed description of cost elements see DSL cost database see model in Appendix III.

3.5 ADSL Model

In this section we will calculate the CAPEX for an upgrade scenario for ADSL. As mentioned in section 3.3, the level of infrastructure and operator type has great influence on the deployment cost. Based on the assumption in section 3.3 the following scenario would be typical for the cost of ILECs (Incumbent Local Exchange Carriers) / CLECs (Competitive Local Exchange Carriers) that need to establish backbone network connections between local exchanges where equipment is hosted. For comparison and conformity with cable technology, we neither include access charges for the local loop nor rental price of hosting equipment in local exchanges but include the cost of the customer premises equipment (CPE) .

Due to the limited transmission speed of ADSL (i.e. 8 Mb/s maximum downstream), only the first two service profiles are examined.

3.5.1 Cost Structure

The simulation reveals a very comparable deployment cost in urban and suburban areas, while the civil work involved in establishing a new backbone connection in rural areas pushes increases the rural cost. This would suggest that the deployment cost of ADSL in areas with existing backbone connections does not differ much. This fact is among other due to technology maturity and product diversity, where rural equipment, such as smaller DSLAMs, now is available at similar pr. user prices.

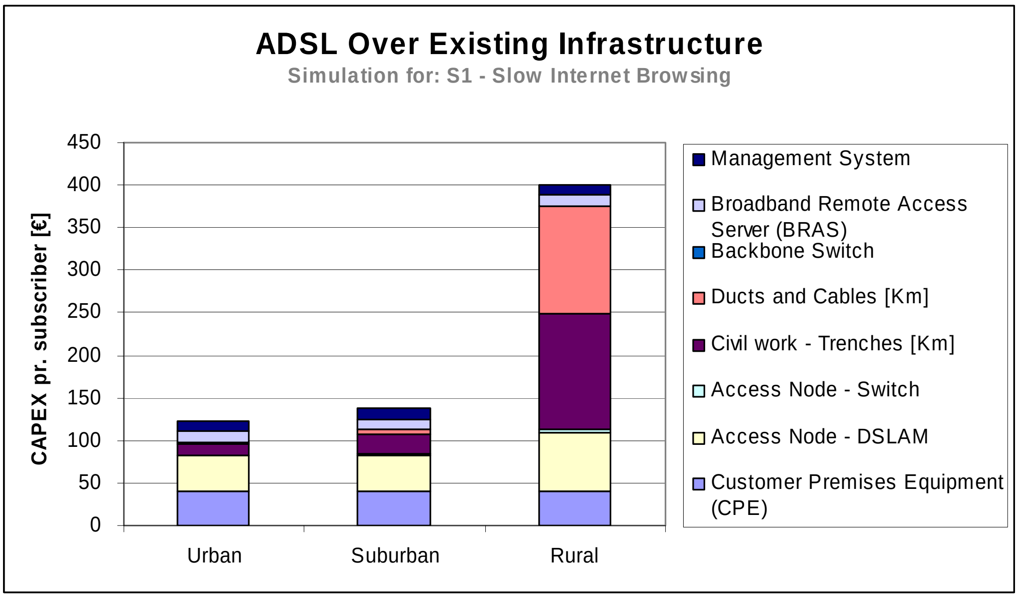


Figure 10: Breakdown of cost structures for ADSL (SP1)

3.5.2 Cost Comparison

By examining different service profiles we wish to examine the effect of development in service offerings. As Figure 14 shows, both urban and suburban scenarios share similar costs for both low and high speed internet connections. However, in the rural side it becomes evident that increased transmission speeds decrease reach and therefore increases the number of access nodes and therefore the dominating cost of establishing backbone connections.

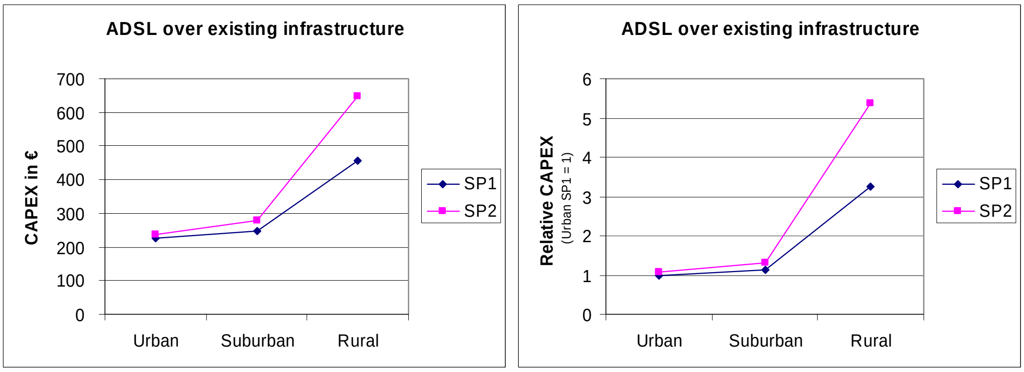


Figure 11: Comparison of ADSL CAPEX for different scenarios

3.5.3 Findings

In the preceding chapter we have examined CAPEX cost structures involved in offering slow and high speed internet browsing with ADSL technology over an existing PSTN infrastructure. The simulation therefore relates to the development of the DSL market for the past few years, where operators were deploying ADSL and gradually screwing up for speed but not yet widely offering multimedia services.

While the study reveals a relatively even equipment cost for different geographical areas, rural areas are 3-6 more expensive to serve, mainly due to cost of establishing new backbone connections. This backbone cost escalates with higher transmission speeds as the reach of ADSL reduces the maximum cable length below the length of the current PSTN copper cables, resulting in a need for a new more dense backbone network with higher number of smaller aggregation nodes.

Furthermore, the analysis verifies the current trend of increased transmission speeds in urban and suburban ADSL, while rural offerings are expected to remain bound to low speed Internet browsing.

3.6 ADSL2+ Model

Now we run the corresponding scenarios to the ADSL model but for ADSL2+ technology. This scenario would be typical for ILECs / CLECs that wish to offer higher transmission rates e.g. to offer triple-play services. This results in shorter reach, i.e. shorter cable distances, and therefore new aggregation nodes. Since the existing PSTN infrastructure can not house this new equipment, expensive new structures (e.g. street cabinets with electricity) need to be established.

We simulate all four service profiles but in reality service profile 3, Multimedia, would be a natural selection for operators.

3.6.1 Cost Structure

In comparison to the cost structure of ADSL, ADSL2+ has two distinctive features: i) additional cost of establishing and interconnecting new structures, resulting in ii) a steeper cost increase for less densely populated areas

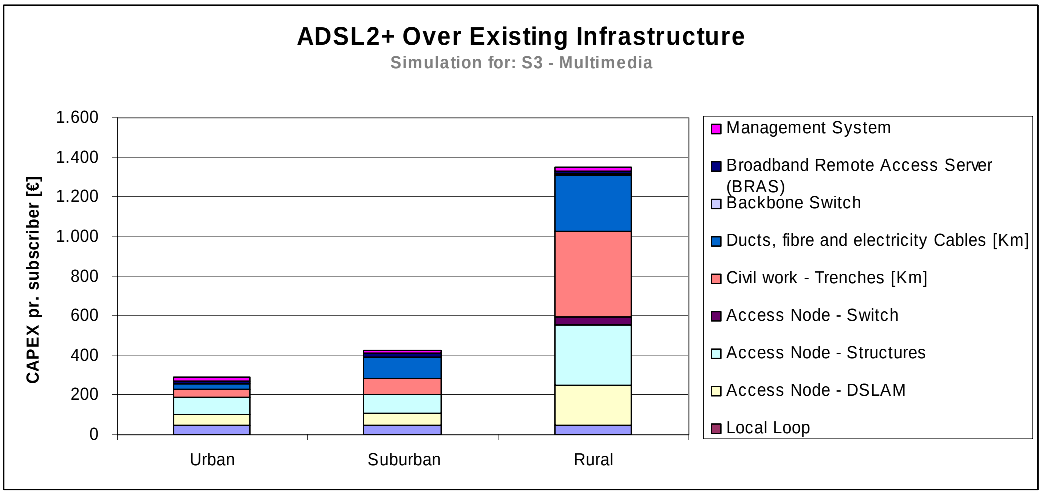


Figure 12: Breakdown of cost structures for ADSL2+ (SP3)

3.6.2 Cost Comparison

In comparison to urban ADSL, we can see that the cost of ADSL2+ in urban areas is roughly double, and relatively non-elastic to service profiles offered. The cost of offering internet browsing is almost identical to ADSL for suburban and rural areas but the rate/reach restrictions of multimedia ADSL2+ increases the deployment cost to 4-10 that of urban ADSL.

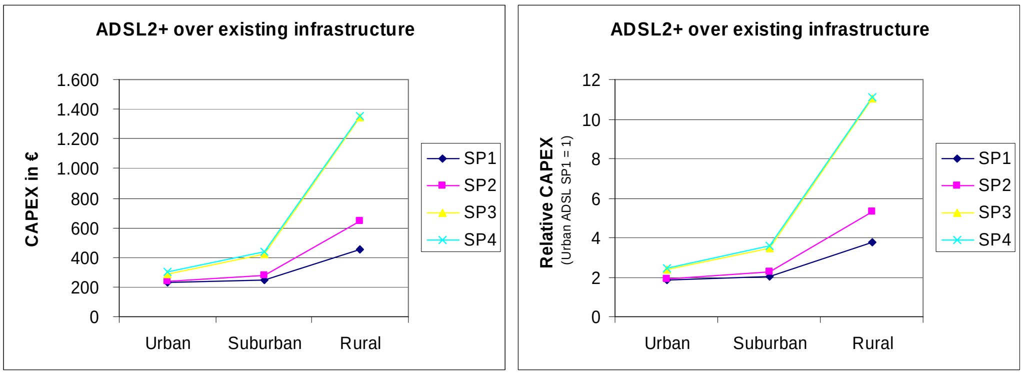


Figure 13: Comparison of ADSL2+ CAPEX for different scenarios

3.6.3 Findings

In the preceding chapter we have examined CAPEX cost structures involved in deployment of ADSL2+. This is in line with the current market situation where operators are upgrading ADSL equipment with ADSL2+ in profitable areas. By upgrading, operators can gain a competitive edge on the market (by offering higher speeds) or by introducing multimedia services. The analysis reveals a clear window of opportunity for ADLS2+ in urban and suburban areas where deployment cost is 2-4 times that of ADSL.

While cost increases in suburban and rural areas can hinder deployment, customers living in the vicinity of existing PSTN structures can be offered ADSL2+ at close to urban prices, resulting in a gap between offers that customers in the same area get. This is due to the dominating cost of civil work, ducts and cables, and new structures closer to customers living further away.

4. Cost analysis for Cable Networks

4.1 General Description

A Hybrid Fibre-Copper (HFC) network is designed as described by the figure below:

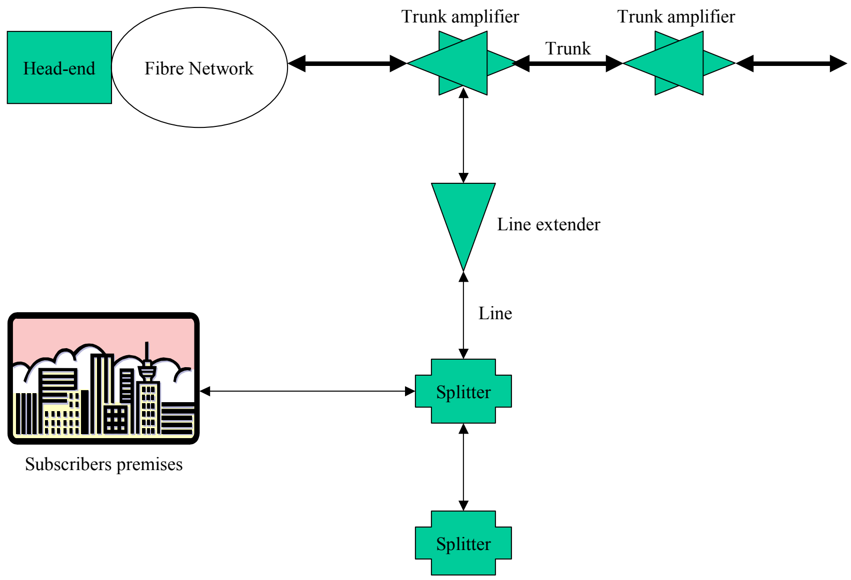


Figure 14: HFC network overview

The main functionality of existing Cable networks, is broadcasting of analogue and digital television content. As such, these cable infrastructures have been established in many urban areas where coaxial cables generally connect homes in a tree topology, providing one-way broadcasting of the frequency range from 88 to 860 MHz. Like PSTN, cable infrastructures can be upgraded to offer broadband connectivity resulting in considerably lower initial investment compared to technologies that require a new physical infrastructure. Since cable is a shared medium (i.e. several homes share a branch from a tree topology) the network must be broken down into smaller access segments, which share the available bandwidth. For this reason the amount and nature of traffic can greatly affects the design and dimensioning of the network.

Characteristic features of HFC are the wide frequency spectrum that the existing cable infrastructure can carry over long distances, and shared medium resulting in natural broadcasting capabilities. The main weakness of HFC networks is the transmission limitations due a shared physical medium.

Due to the lack of cable infrastructure in suburban and rural areas, HFC broadband networks are most common in urban settings, where they provide a horizontal (infrastructure) competition to DSL. HFC networks are generally not considered for green-field deployment.

4.2 Technical Description

Many technical variants exist but the most are based on using the frequency band from 5-65 Mhz for upstream traffic and a portion of the downstream broadcasting channels for IP traffic (see Figure 18). The downstream frequency is divided into 7 to 8 MHz channels, where each channel can carry on television station (AM-VSB modulation) or roughly 40 Mb/s data using QAM64 modulation. The most widespread technical solution for HFC is based on the DOCSIS 2.0 standard.

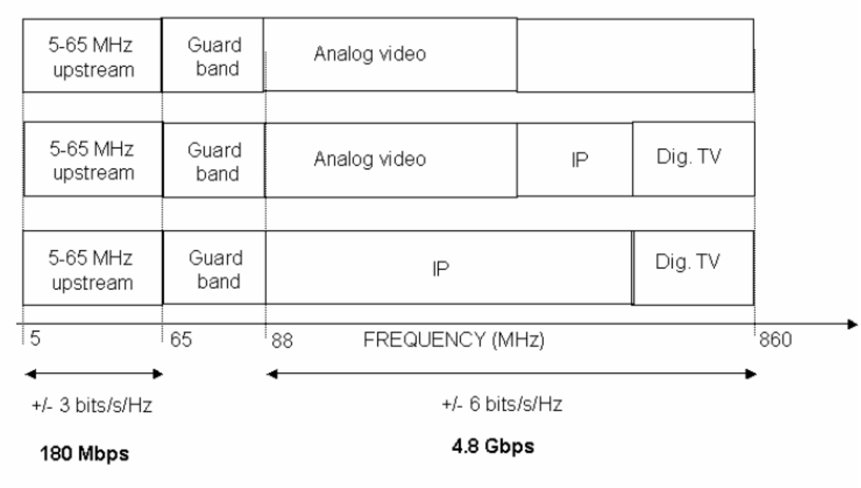


Figure 15: Bandwidth allocation and capacity in HFC networks [2]

4.3 Main Cost Components

When upgrading a cable network to broadband HFC, the required investment consists of the following main components:

- Customer Premises Equipment
  A cable modem is required, usually requiring professional labour for installation.
- Upgrade coaxial network
  Divide the coaxial network into access segments and exchanging one-way components
- Fibre network
  Establish a backbone fibre network to distribution points (access segments)
- Head-end
  Establish hardware equipment in a centralised location

In comparison to DSL technology, a larger part of the HFC deployment cost stems from upgrading the physical infrastructure. Further more, the deployment cost is highly related to deployment size, and split-up into access zones. This is due to a common head-end for all customers rather than more localized equipment in e.g. DSL.

4.4 Scenario Description

We will consider the deployment of HFC in an upgrade scenario where we assume an existing cable infrastructure. We are interested in examining how the deployment cost is affected by changes in service offering in the three geographic scenarios. The scenario is otherwise compatible to that for the DSL models described in Section 3.3.

4.5 HFC Model

In this section we will calculate the required CAPEX for an HFC upgrade scenario. As mentioned above, deployment cost of HFC networks is sensitive to traffic characteristics where increased traffic results in fewer customers pr. branch and thus higher number of distribution points. Additionally the head-end equipment is dimensioned based on throughput and is therefore more expensive for high transmission rates. The details of the scenario and assumptions as well as a demonstration of the calculation can be seen in Appendix I.

4.5.1 Cost Structure

The cost analysis of HFC networks reveals a more concentrated distribution. The cost is dominated by upgrades to the coaxial network, where new structure requires new cable, amplifiers and splitters. HFC network capacity and networks are dimensioned based on a predefined service level they can provide a maximum number of customers. A network designed for a maximum 50% uptake, has a relatively fixed price unrelated to number of actual customers (apart from CPE which is based on no of subscribers). Operators are therefore more contingent upon good planning and dimensioning, and then gathering customers to fill the maximum design limit. For the same reason price pr. subscriber is variable and elastic.

The simulation of Figure 19 assumes 50% maximum uptake and 25% actual uptake.

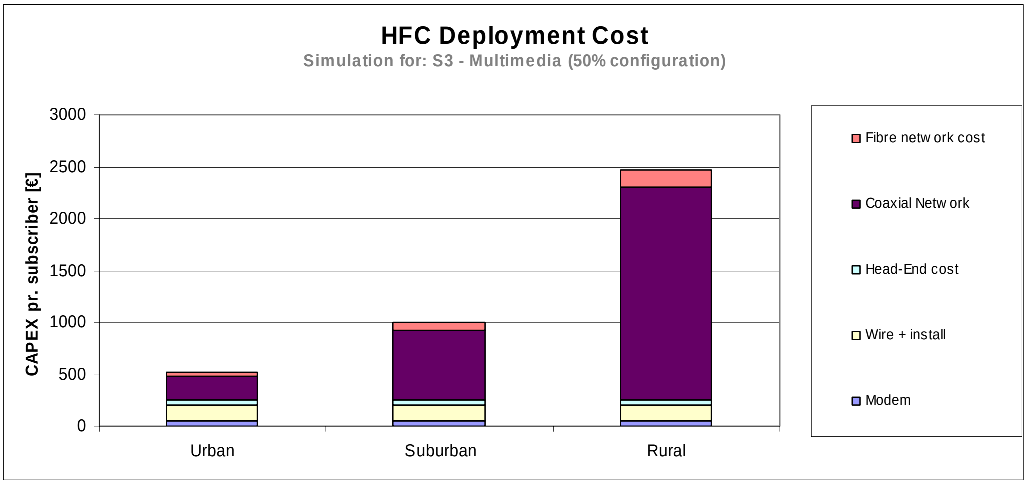


Figure 16: Breakdown of cost structures for HFC upgrade scenario (SP3)

4.5.2 Cost Comparison

As mentioned before, the lack of cable infrastructure in rural areas makes them unrealistic. For the urban and suburban areas the effect of increased traffic affects the size of access segments, increasing the network cost. Additionally increased throughput in cable networks has to be met with additional ports in head-end equipment resulting in additional cost.

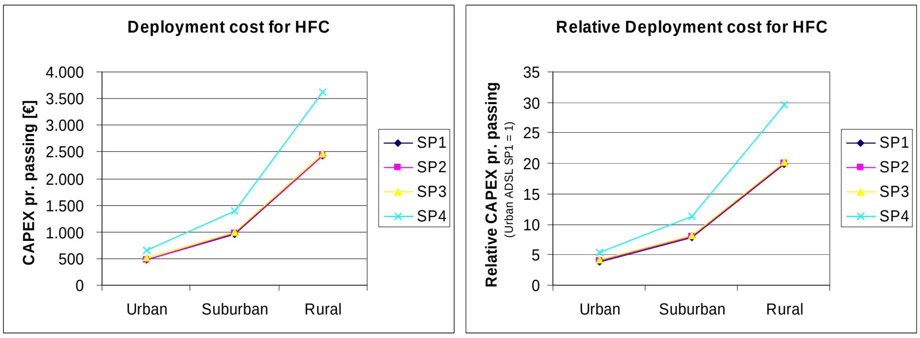


Figure 17: Comparison of HFC CAPEX for different scenarios

4.5.3 Findings

Our analysis verifies the current trend of cable networks being upgraded to offer data communication. The cost comparison indicates a 3-4 times higher upgrade cost than for ADSL SP1 scenario. Given the strengths of cable networks for broadcast services, HFC have a competitive edge in triple-play services.

5. Cost analysis for FTTH

5.1 General Description

Fibre has already become a dominant medium in metro and backbone networks. Fibre-to-the-Home (FTTH) is an umbrella term used for emerging access networks that uses optical fibre in the first/last mile. In techno-economic sense, the advantage of FTTH networks over other telecommunications networks is their long reach and extensive capacity. Fibre has a virtually unlimited bandwidth capacity and is therefore capable of meeting increasing traffic demand of multimedia services and thus providing a "future-safe" medium that outperforms all other know media. With fibre cable prices dropping below that of copper, fibre provide a natural choice for Greenfield deployment.

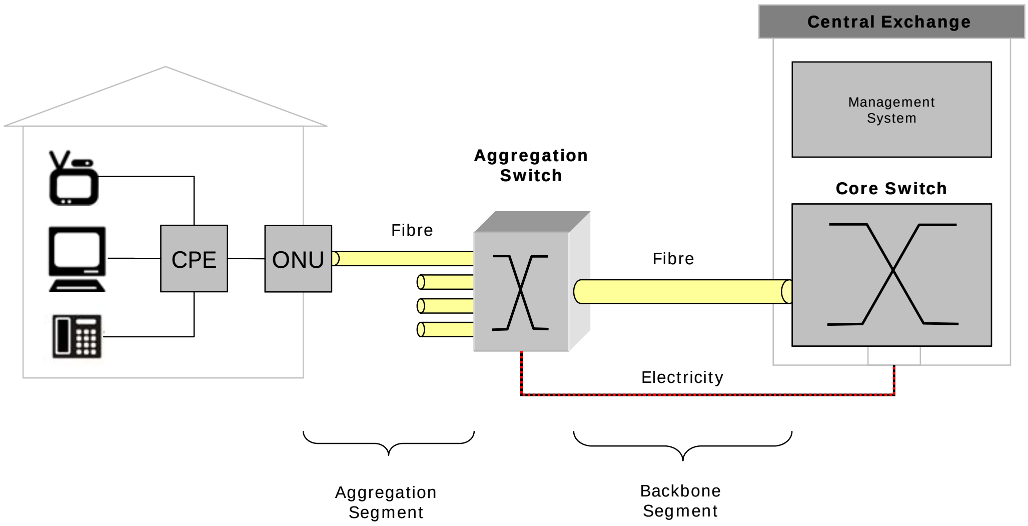


Figure 18: Active FTTH network overview

5.2 Technical Description

Several network architectures and technical implementations of FTTH exist as the technology is still being refined and developed. However, in general, the variants can be categorised as either Active Star, or Passive Optical Networks (PON). The main difference, as the name implies, is that active networks connect each home to electricity fed equipment, such as a switch, while several fibres are passively coupled together in PONs. The PON architecture bears a very close resemblance to that of coax-based HFC, both in geometry and also in many of the protocol details [8] and is the preferred solution of telecoms. Active star is more expensive both in terms of CAPEX and OPEX due to active components in the network but offers a dedicated connection and advantages in Operation & Management (O&M). Another open issue is the question of underlying transmission protocol, where the telecom originated Asynchronous Transfer Mode (ATM) with fixed size cells, competes against packet based Ethernet standards.

5.3 Scenario Description

In the remainder of this study we will simulate a Greenfield deployment of an Ethernet based active star network structure, like the one depicted in Figure 25. This choice is e.g. taken to reflect the choice of Municipal Electric Companies, which constitute the majority of commercial networks and trials in Scandinavia.

In this scenario, we make the assumption that the municipality has the advantage of existing electricity feeds for aggregation nodes. Additionally, there might be operational synergies that we do not account for, both in deployment (i.e. sharing of ducts with electricity cables) and operation & maintenance.

5.4 Main Cost Components

FTTH cost components differ based on the technical solution selected. PON cost components resemble that of HFC while for active star the required investment consists of the following main components:

- Customer Premises Equipment

  An ONU (Optical Network Unit) terminates the optical signals at the user side. Depending on the solution and services offered, other equipment may be needed.
- Fibre Access Network

  Cable, ducts and civil work required to connect each home to an aggregation node.
- Aggregation Node

  Cabinet and Switch that terminates the fibre connection and aggregates them towards a central exchange.
- Fibre Backbone Network

  Cable, ducts and civil work required to connect aggregation nodes to a central exchange.
- Service Node equipment

  Core switches and routers for backbone connectivity. Additionally, management system and BRAS are required.

Due to all the hardware spread around the deployment area (i.e. in aggregation nodes), the OPEX of active star is higher than for PON.

5.5 The FTTH Model

In this section we will calculate the required CAPEX for a Greenfield scenario. As mentioned above, deployment cost of FTTH networks is sensitive to civil work, ducts, and cables and therefore we will additionally perform a cost optimisation to find the optimal network design. The details of the scenario and assumptions as well as a demonstration of the calculation can be seen in Appendix II.

5.5.1 Cost Structure

When establishing a new FTTH network, the dominant cost component will inevitably be civil work, ducts, and cables. As Figure 22 shows, the cost of civil work and cables in the access segment escalates in the suburban and rural scenario, due to longer distances. Additionally, in rural settings, ducts and cables in the backbone segment result in a higher CAPEX than the whole deployment cost of FTTH in urban settings.

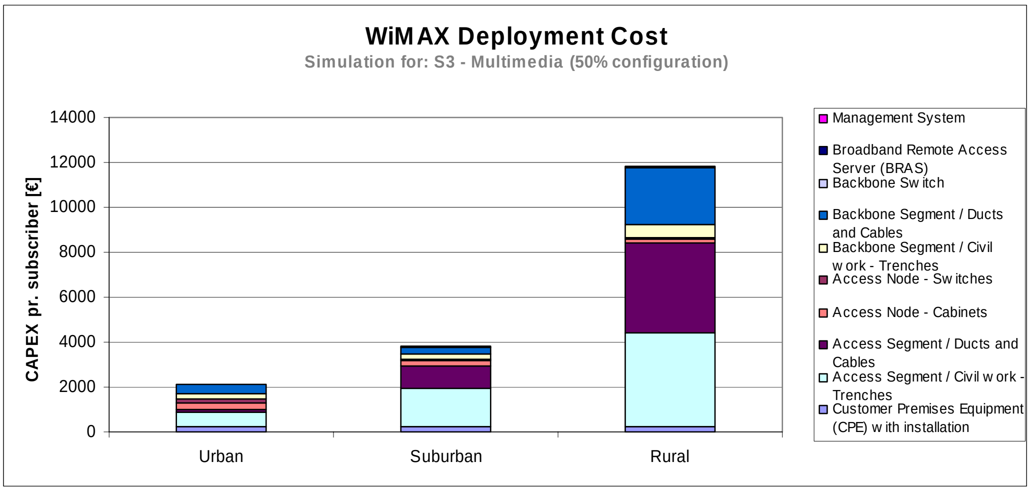


Figure 19: Breakdown of cost structures for FTTH greenfield scenario.

5.5.2 Cost Optimisation

Generally, when designing and implementing a Greenfield infrastructure there are decision parameters that can greatly affect the cost of the network. For FTTH one of these is the average length of fibre in the aggregation segment. Depending on the cost ration of fibre and aggregation node equipment, there exists an fibre distance that minimises the deployment cost. This length varies for different settings and scenarios. In Figure 23 the deployment cost of the presented FTTH scenario is plotted against the length of fibre to the first aggregation node / street cabinet.

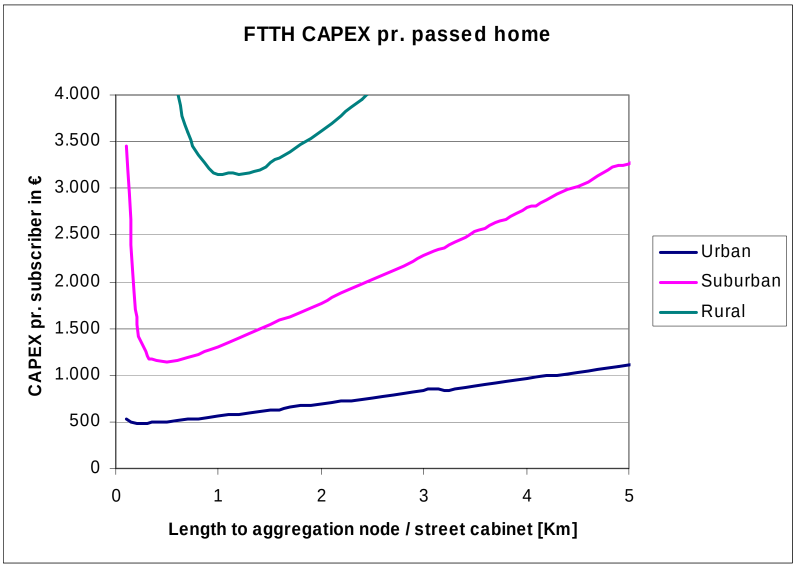


Figure 20: Cost optimisation for the design of FTTH

5.5.3 Cost Comparison

When deploying a FTTH infrastructure, all homes in a deployment area are connected with a fibre cable, independent of take-up rate. This means that the dominant cost component of civil work, ducts and cables is fixed. The result is that the more subscribers a FTTH operator can attain, the lower the cost pr. subscriber is. Another way of measuring the cost of FTTH is therefore pr. passed home, rather than pr. subscriber.

Unlike the transmission mediums analysed in the previous chapters, fibre deployment is unrelated to the amount and type of traffic transmitted as well as distance. As a consequence, we do not differentiate between service profiles in the cost comparison.

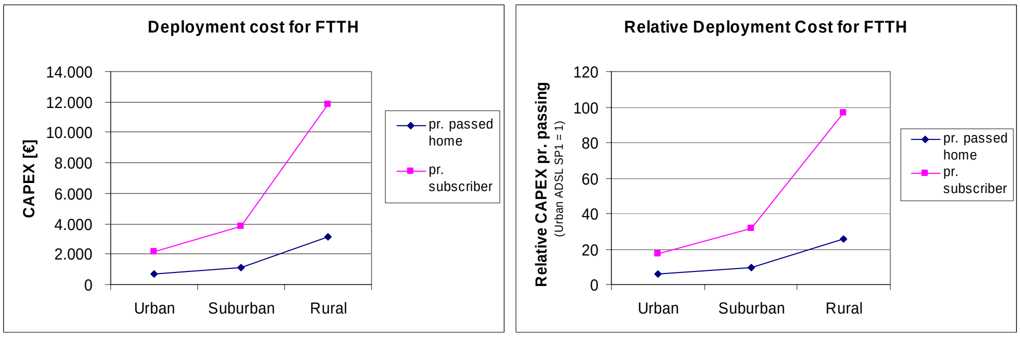


Figure 24: Comparison of FTTH CAPEX for different scenarios

5.5.4 Findings

Our analysis shows that roughly 60% of the CAPEX for FTTH in all scenarios is due to civil work, ducts, and cables. The result verifies the current trend of fibre in areas that for some other reason need to be dug up. The analysis also highlights the need for optimisation in network design as well as the effect of take-up rate on the cost pr. subscriber.

6. Cost analysis for WiMAX

6.1 General Description

A fixed wireless access network architecture can be described by the following figure:

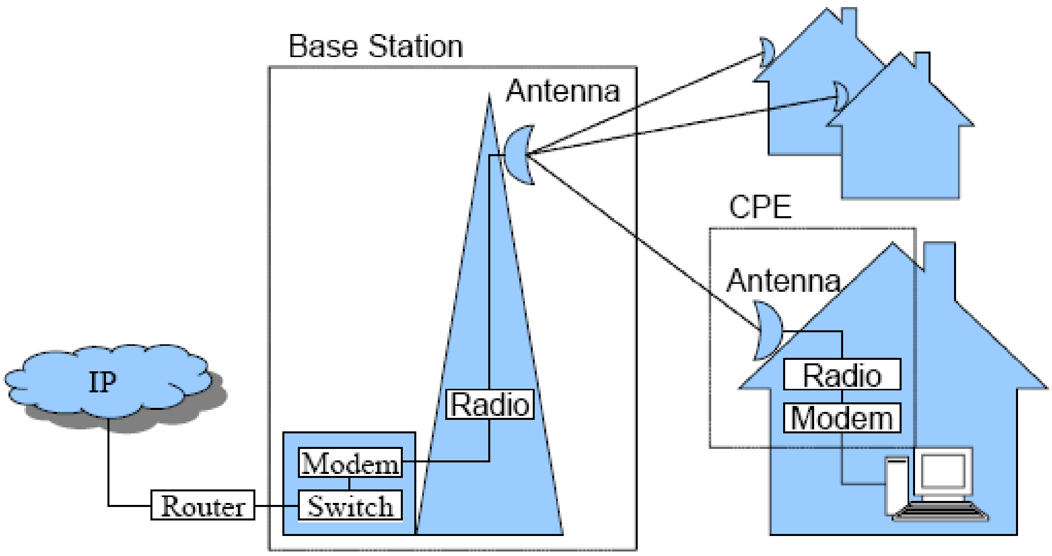


Figure 25: Example of a fixed wireless network architecture (Ibe 2002, p.7)

6.2 Technical Description

The approach is to use the same head-end architecture and fibre network costs then to replace the cost relative to the coaxial networks by the base station and households equipments of WIMAX network.

6.3 Main Cost Components

This technology being still quite new, it's hard to estimate the real cost of non-existing components or prototypes. These costs are estimated assuming a successful trend of this technology deployment.

Base station

The cost of installation and equipment of a base station is reduced to the following items

Base station	40 000,00 €
Sector antenna	3 000,00 €
Total base station	43 000,00 €
Total bandwidth (Mb/s)	320

6.4 The WiMAX Model

In this section we will calculate the required CAPEX for a greenfield scenario. Deployment cost of WiMAX networks is to traffic characteristics where increased traffic e.g. results in higher number of sector antennas and/or smaller coverage area pr. base station. The details of the scenario and assumptions as well as a demonstration of the calculation can be seen in Appendix II.

6.4.1 Cost Structure

The simulation reveals a relatively simple cost structures where the base station equipment along with CPE dominates the cost. The study also reveals that despite the focus on MiMAX deployment in rural areas, it can provide a competitive solution in urban areas too.

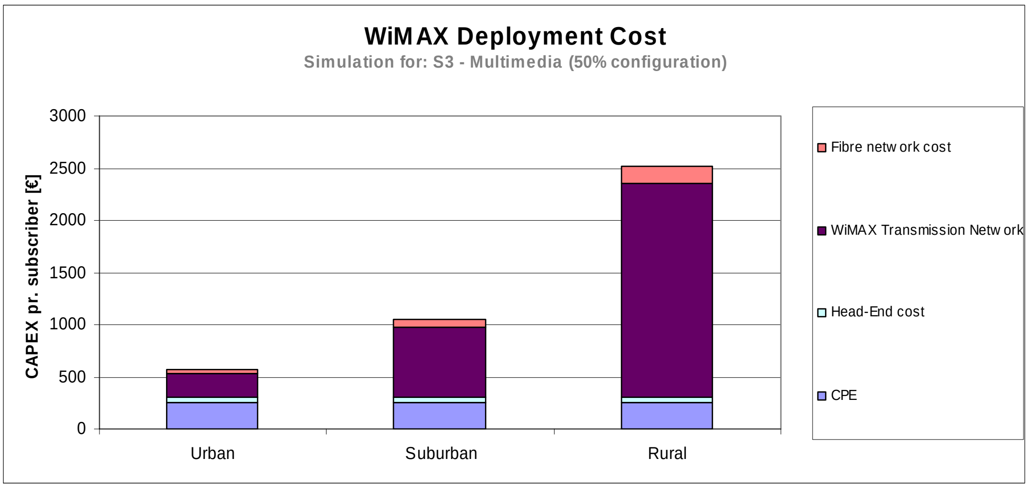


Figure 21: Breakdown of cost structures for WiMAX greenfield scenario.

6.4.2 Cost Comparison

The most obvious conclusion when comparing the cost of different service profiles for WiMAX is that the technology is not well suited for high transmission rates. The cost of SP4 is 400% more expensive than SP1. Despite this, WiMAX provides an inexpensive solution to low speed transmission rates where other infrastructure is missing.

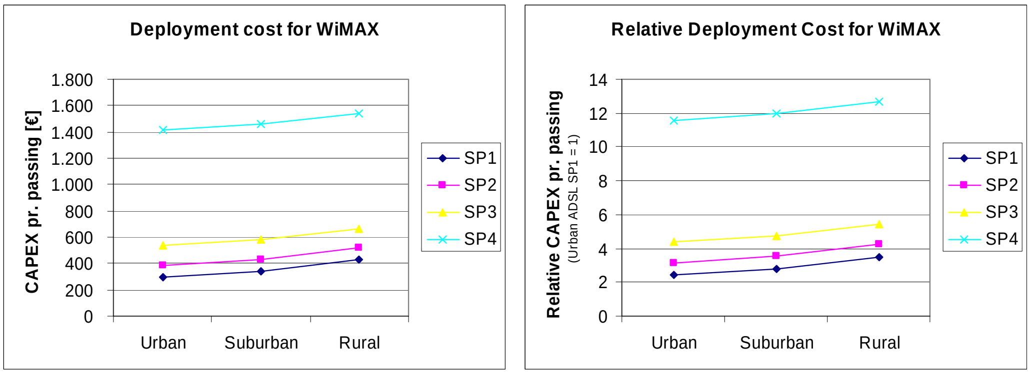


Figure 22: Comparison of HFC CAPEX for different scenarios

6.4.3 Findings

Our analysis highlights the competitive nature of WiMAX as a short time solution for providing internet connectivity. The mild increase in cost for rural areas indicates a clear window of opportunity for the technology. The drawback of WiMAX is the temporary nature due to expensive transmission pr. bit and thus high upgrade costs for increased throughput.

7. Comparison of Deployment Cost

7.1 General Description

In this study we have compared calculated the deployment cost of different technologies in similar geographic settings and for similar transmission / service requirements. Although not directly comparable, the aim is to map technologies to deployment settings and aid in the understanding of influential parameters. The developed techno-economic model will thus provide an invaluable input to further analysis, e.g. sensitivity analysis. However, in this deliverable we will have to suffice with a comparison of the technologies and scenarios described earlier.

7.2 Cost Comparison

The study reveals and verifies the current trend of DSL & Cable dominance in the urban market segment, where existing infrastructure facilitates inexpensive equipment upgrades. There is a fundamental trade-off between reach and capacity in most access technologies and extending the coverage of xDSL technology to provide higher capacities for less populated areas will be expensive and the study reveals a clear window of opportunity for wireless technologies in rural and suburban areas.

Future service scenarios are expected to demand increasing transmission capabilities and with the introduction of triple-play services, substantial new infrastructure investment is needed. For these scenarios, comparison of deployment cost becomes more subjective. While wireless and copper/coaxial based infrastructures require less capital investment it is unrealistic since fibre based infrastructures provide a more future safe solution. For these new infrastructures, optimisation of network structures is critical and merely replacing copper with fibre would result in substantially higher cost than otherwise required.

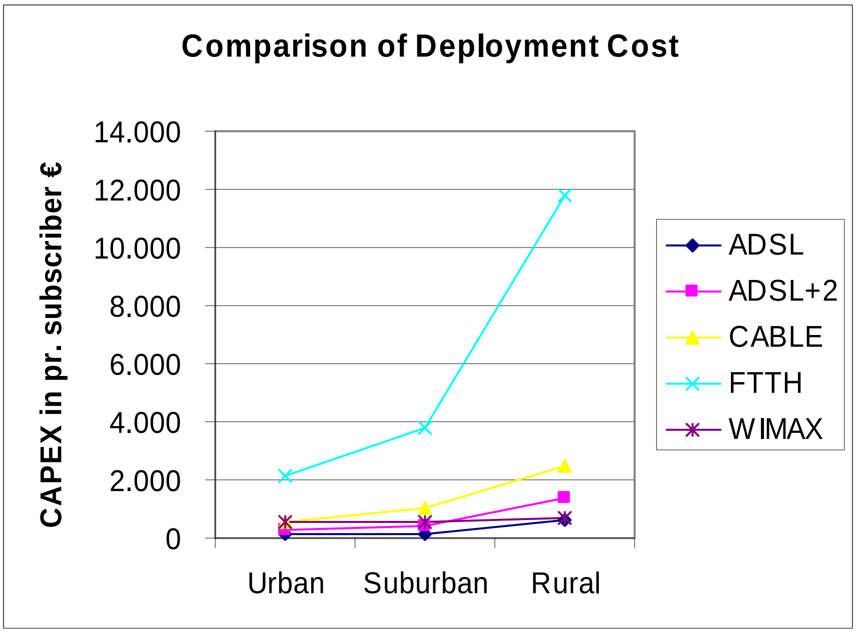


Figure 23: Comparison of technologies for service profile 3

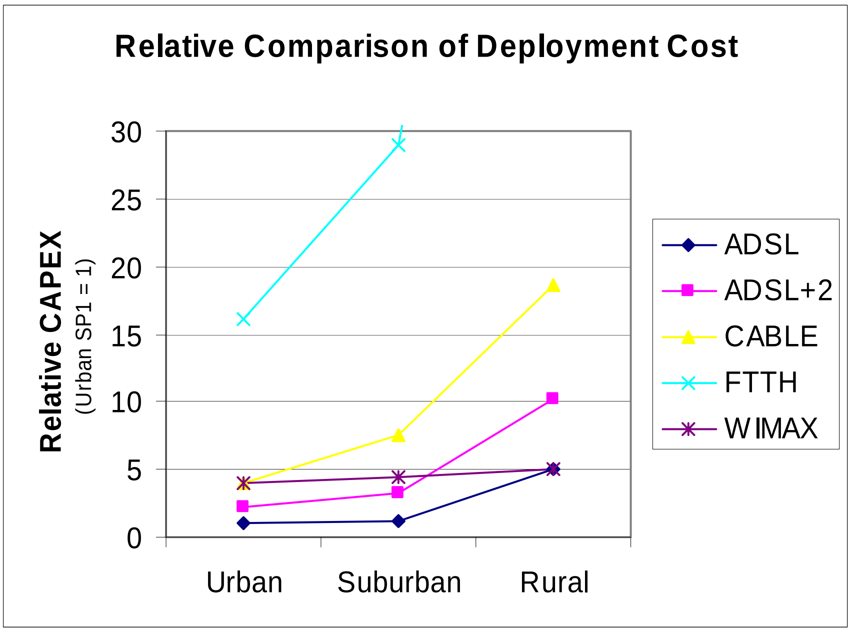


Figure 24: Relative CAPEX comparison of all technologies for service profile 3

7.3 Conclusion

In the preceding chapter we have examined CAPEX cost structures involved in deployment of DSL, HFC, FTTH and WiMAX. The study reveals difference in cost structures between technologies and their ability to handle varying services and transmission speeds. The study reveals that currently all technologies are competitive in the urban settings, with the exception of FTTH, which is only feasible if other groundwork is carried out at the same time.

For the suburban and rural areas, there will be a gap between those living in the vicinity of existing telecommunications infrastructure, such as PSTN, and those living further away. Although detached DSLAMs have the possibility of decreasing this gap for DSL, the additional cost of establishing a backbone fibre connection to these aggregation points results in a ten times higher cost. For these users, WIMAX provides and excellent short-term solution for providing internet connectivity. The drawback of WiMAX is the temporary nature due to expensive transmission pr. bit and thus high upgrade costs for increased throughput.

In all areas, FTTH provides an expensive but future-proof solution. Our analysis shows that roughly 60% of the CAPEX for FTTH in all scenarios is due to civil work, ducts, and cables. In rural and suburban areas, the result of this could be smaller deployment zones where citizens reduce the cost by participating in ground work, and / or local governments reduce the cost by granting connectivity to established backbone networks.

8. References

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9. Appendix I – Calculations of the HFC model

9.1 Common head-end architecture

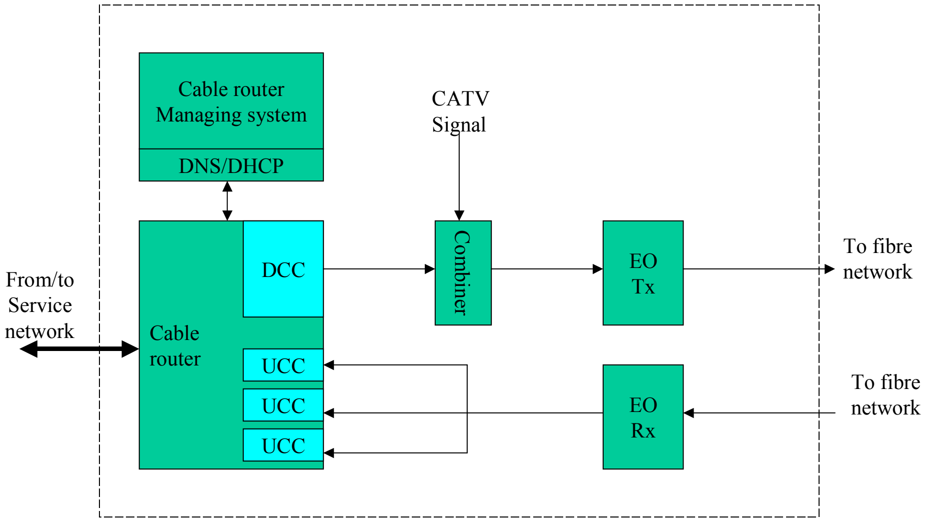

Figure 2: Head-end synoptic

The number of required routers is driven either by the number of ports or by the throughputs, depending on the traffic assumptions taken:

One port is always reserved to the service network output, the others are used by the downstream and upstream ports in a ratio which can vary between 1 to 1 (symmetrical traffic driven mainly by peer-to-peer communications) and 1 to 10 (asymmetrical traffic in a centralised architecture).

We assume a cable router is able to manage 32 downstream and upstream ports through the DCC (Downstream Controller Card) and UCC (upstream Controller Card) boards with the following criteria.

The number of subscribers is calculated with the average bitrates of the different kind of services.

Service S1	Upstream	Downstream
CMTS capability	15	50
S1:25%		
Subscribers	2250	750
Ports	8	24
Number of CMTS	1	1
S1:50%		
Number of CMTS	3	3

Service S2	Upstream	Downstream
CMTS capability	15	50
S2:25%		
Subscribers	281,25	93,75
Ports	8	24
Number of CMTS	11	11
S2:50%		
Number of CMTS	22	22

Service S3	Upstream	Downstream
CMTS capability	15	50
S3:25%		
Subscribers	112,5	37,5
Ports	8	24
Number of CMTS	28	28
S3:50%		
Number of CMTS	56	56

Service S4	Upstream	Downstream
CMTS capability	15	50
S4:25%		
Subscribers	3,75	12,5
Ports	24	8
Number of CMTS	278	250
S4:50%		
Number of CMTS	556	500

The cable router managing system is managing the functions needed in a TCP/IP network such as dynamical IP addresses assignment, domain name and addresses range used by the server. Using DHCP (Dynamic Host configuration Protocol) and DNS (Domain Name Server), the cable router managing system may be shared between 50 cable routers.

The combiner is the hardware equipment mixing the downstream broadband traffic and the cable TV signal.

EO Tx and EO Rx are the analogue electro-optical transceivers.

9.2 Optical nodes distribution

Cable companies use a frequency spectrum from 5 to 65 MHz for upstream communication and 50 to 860 MHz for the downstream signals divided into 7 to 8 MHz channels used by one television station (AM-VSB modulation);

Only part of this capacity is used for television broadcasting, between 20 to 60 MHz of upstream and 100 to 300 MHz of downstream bandwidth is available for broadband services.

With a signal to noise ratio of 44 dB and using a QAM64 modulation, these unemployed channels can provide 40 Mb/s data rate possibly used by new digital TV channels (around 8 TV stations per channel) or broadband services. Assuming this unemployed bandwidth is dedicated to broadband services, a 1.5 Gb/s capacity is available for downstream communications.

For upstream communication, the upstream spectrum is impaired mainly by Ingress and Impulse noise, whereas the CNR remains within acceptable limits [cable doc]. Overall the channel capacity can be estimated to 3 bits/sec/Hz, therefore a total capacity This capacity having to be shared amongst many subscribers using interactive services is insufficient. It is the reason why the coaxial network is divided in sub-areas interconnected by a high capacity optical network building together the HFC (Hybrid Fibre Coax) network.

9.3 Fibre network

For the fibre networks, we consider:

- Maximum fibre length is 14 km.
- Use a cable including 144 fibres.
- One cable per duct.
- 6 fibres per optical node.

We consider a fibre cost constituted by duct and fibre of 17 euros per meter.

Then remains the extra costs linked to the subscribers' connections

9.4 Main Cost Components

Assuming the following general assumptions, we can start to evaluate the cost structure for each domain (head-end, fibre network, coaxial network and subscriber's equipments) for several kinds of services.

Type	Upstream(Mb/s) nominal rate	Downstream(Mb/s) nominal rate	Upstream(Mb/s) average rate	Downstream(Mb/s) average rate	Contention rate
S1: Slow internet browsing	0,2	2	0,01	0,07	30
S2: Fast internet browsing	0,8	8	0,05	0,53	15
S3: Multimedia	2	20	0,13	1,33	15
S4: Peer to peer	20	20	4,00	4,00	5

This cost simulation is done using the generic hypothesis of a town of 100 000 citizens with both penetration rates of 25 and 50 percents.

9.4.1 Head end components

For each downstream port, we use:

Equipment	Number	Unitary cost	Total
Optical transmitter (including install.)	1	1 360,00 €	1 360,00 €
Total downstream port			1 360,00 €

For each upstream port, we use:

Equipment	Number	Unitary cost	Total
Optical receiver (including install.)	1	560,00 €	560,00 €
Total upstream port			560,00 €

The cable routers are composed of 24 downstream units and 8 upstream units allowing the best filling of the cable router capacities for the services S1 to S3.
For each cable router (S1/S2/S3), we evaluate:

Equipment	Number	Unitary cost	Total
Upstream link	8	560,00 €	4 480,00 €
Downstream link	24	1 360,00 €	32 640,00 €
Total			37 120,00 €

One system management is sufficient for up to 50 cable routers. We are then able to estimate the global cost of a head end for S1 to S3.

Equipment S1/25%	Number	Unitary cost	Total
Cable router management system for up to 50 CMTS	1	22 000,00 €	22 000,00 €
Cable router (including install.):S1/25%	1	10 000,00 €	13 888,89 €
Total Cable router:S1/25%			35 888,89 €
Equipment S1/50%			
Cable router management system for up to 50 CMTS	1	22 000,00 €	22 000,00 €
Cable router (including install.):S1/50%	3	10 000,00 €	27 777,78 €
Total Cable router:S1/50%			49 777,78 €

	S1:25%	S1:50%
Total head end	87 444,44 €	152 888,89 €

Equipment S2/25%	Number	Unitary cost	Total
Cable router management system for up to 50 CMTS	1	22 000,00 €	22 000,00 €
Cable router (including install.):S2/25%	11	10 000,00 €	111 111,11 €
Total Cable router:S2/25%			133 111,11 €
Equipment S2/50%	Number	Unitary cost	Total
Cable router management system for up to 50 CMTS	1	22 000,00 €	22 000,00 €
Cable router (including install.):S2/50%	22	10 000,00 €	222 222,22 €
Total Cable router:S2/50%			244 222,22 €

		S2:25%	S2:50%
Total head end		545 555,56 €	1 069 111,11 €

Equipment S3/25%	Number	Unitary cost	Total
Cable router management system for up to 50 CMTS	1	22 000,00 €	22 000,00 €
Cable router (including install.)	28	10 000,00 €	277 777,78 €
Total Cable router:S3/25%			299 777,78 €
Equipment S3/50%	Number	Unitary cost	Total
Cable router management system for up to 50 CMTS	2	22 000,00 €	44 000,00 €
Cable router (including install.)	56	10 000,00 €	555 555,56 €
Total Cable router:S3/50%			577 555,56 €

		S3:25%	S3:50%
Total head end		1 330 888,89 €	2 639 777,78 €

For S4 we have to change the CMTS configuration in order to handle better the upstream requirements of this greedy service.

For each cable router S4, we evaluate:

Equipment	Number	Unitary cost	Total
Upstream link	24	560,00 €	13 440,00 €
Downstream link	8	1 360,00 €	10 880,00 €
Total			24 320,00 €

Equipment S4/25%	Number	Unitary cost	Total
Cable router management system for up to 50 CMTS	6	22 000,00 €	132 000,00 €
Cable router (including install.)	278	10 000,00 €	2 777 777,78 €
Total Cable router:S4/25%			2 909 777,78 €
Equipment S4/50%	Number	Unitary cost	Total
Cable router management system for up to 50 CMTS	12	22 000,00 €	264 000,00 €
Cable router (including install.)	556	10 000,00 €	5 555 555,56 €
Total Cable router:S4/50%			5 687 555,56 €

	S4:25%	S4:50%
Total head end	2 909 777,78 €	5 687 555,56 €

9.5 Optical nodes distribution

For the coaxial network, we consider a typical architecture composed by:

Hypothesis	
250	homes per coaxial trunk amplifier (max)
4	coaxial branches per trunk amplifier.
3,5	coaxial distribution amplifiers per coaxial branch.
3	splitters between distribution amplifiers

The bandwith constraints are the following:

1500	Max Downstream bitrate (Mb/s)
150	Max Upstream bitrate (Mb/s)

The study is done for an area of 100 000 potential subscribers being the optimal size for the head-end. The head-end is in the centre of this area.

According to the hypothesis described above, we can define typical optical node architecture:

Equipment	Number	Unitary cost	Total
Trunk amplifier (including install.)	4	630,00 €	2 520,00 €
Distribution amplifier (including install.)	56	428,00 €	23 968,00 €
Splitter (including install.)	216	10,00 €	2 160,00 €
Optical receiver	1	800,00 €	800,00 €
Optical transmitter	1	500,00 €	500,00 €
Total			29 948,00 €

500	Subscribers per optical nodes (25%)
1000	Subscribers per optical nodes (50%)
50	Optical nodes allowing a max penetration rate of 50%

Assuming the distribution of the subscribers listed above, we are able to compute the relevant cost of an optical node in the different kinds of area: downtown, suburban and rural.

Area Type	Downtown	Urban	Rural
Subscriber density (home/km^2)	10000	1000	100
HE area	10	100	1000
Optical node area (km^2)	0,2	2	20
C (m)	447	1414	4472
Cable length (m)	28870	91295	288701
Coax cable cost (per m.)	7,00 €	7,00 €	7,00 €
Total cable cost	202 090,85 €	639 067,40 €	2 020 908,55 €
Equipments cost	29 948,00 €	29 948,00 €	29 948,00 €
Total optical node	232 038,85 €	669 015,40 €	2 050 856,55 €

A quick check of the upstream and downstream bitrates allows to determine this architecture is unacceptable for the peer-to-peer services. For this rich service, we have to use lower hypothesis:

18	Subscribers per optical nodes (25%)
36	Subscribers per optical nodes (50%)
1388	Optical nodes allowing a max penetration rate of 50%

And then a lighter architecture for the optical nodes:

Area Type	Downtown	Urban	Rural
Subscriber density (home/km^2)	10000	1000	100
HE area	10	100	1000
Optical node area (km^2)	0,007204611	0,07204611	0,720461095
C (m)	85	268	849
Cable length (m)	1613	5100	16127
Coax cable cost (per m)	7,00 €	7,00 €	7,00 €
Total cable cost	11 289,04 €	35 699,07 €	112 890,37 €
Equipments cost	2 216,00 €	2 216,00 €	2 216,00 €
Total optical node	13 505,04 €	37 915,07 €	115 106,37 €

Total S4	18 744 991,77 €	52 626 117,79 €	159 767 645,69 €

9.6 Fibre network

According to the models of architecture designs described above in this document, we can compute:

Area Type	Downtown	Urban	Rural
Subscriber density (home/km^2)	10000	1000	100
HE area	10	100	1000
C (m)	447	1414	4472
Fibre length (m)	22360,68	70710,68	223606,80
Cost of fibre length (euros)	380 131,56 €	1 202 081,53 €	3 801 315,56 €
Digging cost (euros/m)	60	40	20
Cost of civil works	1 341 640,79 €	2 828 427,12 €	4 472 135,95 €
Total	1 721 772,34 €	4 030 508,65 €	8 273 451,52 €

We assume the fiber length is independent of the number of cells in a first approach
The cost per subscriber's installation is estimated:

Modem	50,00 €
Wire + install	150,00 €
Total subscriber equipment	200,00 €

9.7 Cost per subscriber for the different services

Service S1

	S1:25% configuration		
Subscriber equipment	Downtown Cost	Urban Cost	Rural Cost
Modem	50,00 €	50,00 €	50,00 €
Wire + install	150,00 €	150,00 €	150,00 €
Total subscriber equipment	200,00 €	200,00 €	200,00 €
Head End cost per subscriber	3,50 €	3,50 €	3,50 €
Optical node cost per subscriber	464,08 €	1 338,03 €	4 101,71 €
Fibre network cost per subscriber	68,87 €	161,22 €	330,94 €
Total cost per passing	736,45 €	1 702,75 €	4 636,15 €

	S1:50% configuration		
Subscriber equipment	Downtown Cost	Urban Cost	Rural Cost
Modem	50,00 €	50,00 €	50,00 €
Wire + install	150,00 €	150,00 €	150,00 €
Total subscriber equipment	200,00 €	200,00 €	200,00 €
Head End cost per subscriber	3,06 €	3,06 €	3,06 €
Optical node cost per subscriber	232,04 €	669,02 €	2 050,86 €
Fibre network cost per subscriber	34,44 €	80,61 €	165,47 €
Total cost per passing	469,53 €	952,68 €	2 419,38 €

Service S2

	S2:25% configuration		
Subscriber equipment	Downtown Cost	Urban Cost	Rural Cost
Modem	50,00 €	50,00 €	50,00 €
Wire + install	150,00 €	150,00 €	150,00 €
Total subscriber equipment	200,00 €	200,00 €	200,00 €
Head End cost per subscriber	21,82 €	21,82 €	21,82 €
Optical node cost per subscriber	464,08 €	1 338,03 €	4 101,71 €
Fibre network cost per subscriber	68,87 €	161,22 €	330,94 €
Total cost per passing	754,77 €	1 721,07 €	4 654,47 €

	S2:50% configuration		
Subscriber equipment	Downtown Cost	Urban Cost	Rural Cost
Modem	50,00 €	50,00 €	50,00 €
Wire + install	150,00 €	150,00 €	150,00 €
Total subscriber equipment	200,00 €	200,00 €	200,00 €
Head End cost per subscriber	21,38 €	21,38 €	21,38 €
Optical node cost per subscriber	232,04 €	669,02 €	2 050,86 €
Fibre network cost per subscriber	34,44 €	80,61 €	165,47 €
Total cost per passing	487,86 €	971,01 €	2 437,71 €

Service S3

	S3:25% configuration		
Subscriber equipment	Downtown Cost	Urban Cost	Rural Cost
Modem	50,00 €	50,00€	50,00€
Wire + install	150,00 €	150,00€	150,00€
Total subscriber equipment	200,00 €	200,00€	200,00€
Head End cost per subscriber	53,24 €	53,24 €	53,24 €
Optical node cost per subscriber	464,08 €	1 338,03 €	4 101,71 €
Fibre network cost per subscriber	68,87 €	161,22 €	330,94 €
Total cost per passing	786,18 €	1 752,49 €	4 685,89 €

	S3:50% configuration		
Subscriber equipment	Downtown Cost	Urban Cost	Rural Cost
Modem	50,00 €	50,00 €	50,00 €
Wire + install	150,00 €	150,00 €	150,00 €
Total subscriber equipment	200,00 €	200,00 €	200,00 €
Head End cost per subscriber	53,24 €	53,24 €	53,24 €
Optical node cost per subscriber	232,04 €	669,02 €	2 050,86 €
Fibre network cost per subscriber	34,44 €	80,61 €	165,47 €
Total cost per passing	519,71 €	1 002,86 €	2 469,56 €

Service S4

	S4:25% configuration		
Subscriber equipment	DowntownCost	Urban Cost	Rural Cost
Modem	50,00 €	50,00 €	50,00 €
Wire + install	150,00 €	150,00 €	150,00 €
Total subscriber equipment	200,00 €	200,00 €	200,00 €
Head End cost per subscriber	53,24 €	53,24 €	53,24 €
Optical node cost per subscriber	750,28 €	2 106,39 €	6 394,80 €
Fibre network cost per subscriber	68,87 €	161,22 €	330,94 €
Total cost per passing	1 072,39 €	2 520,85 €	6 978,97 €

	S4:50% configuration		
Subscriber equipment	DowntownCost	Urban Cost	Rural Cost
Modem	50,00 €	50,00 €	50,00 €
Wire + install	150,00 €	150,00 €	150,00 €
Total subscriber equipment	200,00 €	200,00 €	200,00 €
Head End cost per subscriber	52,80 €	52,80 €	52,80 €
Optical node cost per subscriber	375,14 €	1 053,20 €	3 197,40 €
Fibre network cost per subscriber	34,44 €	80,61 €	165,47 €
Total cost per passing	662,37 €	1 386,60 €	3 615,66 €

10. Appendix II – Calculations of the WiMAX model

According to the services definition as described in the HFC chapter, we can compute the number of base stations needed in the different cases:

Service	S1	S2	S3	S4
Bandwidth (Mb/s)	0,073	0,587	1,467	8,000
Potential Subscribers per cell	4364	545	218	40
Number of cells (50%)	12	92	230	1251
Base station (total cost)	516 000,00 €	3956000,00 €	9890000,00 €	53793000,00 €

A new cost per subscriber is then computed and replaces the cost of the coaxial network:

Cost per subscriber 25%	20,64 €	158,24 €	395,60 €	2 151,72 €
Cost per subscriber 50%	10,32 €	79,12 €	197,80 €	1 075,86 €

10.1 *Cost per subscriber for the different services*

Service S1

	S1:25% configuration		
Subscriber equipment	DowntownCost	Urban Cost	Rural Cost
CPE Indoor	250,00 €	250,00 €	250,00 €
Head End cost per subscriber	3,50 €	3,50 €	3,50 €
Wimax cost per subscriber	20,64 €	20,64 €	20,64 €
Fibre network cost per subscriber	68,87 €	161,22 €	330,94 €
Total cost per passing	343,01 €	435,36 €	605,08 €

	S1:50% configuration		
Subscriber equipment	DowntownCost	Urban Cost	Rural Cost
CPE Indoor	250,00 €	250,00 €	250,00 €
Head End cost per subscriber	3,06 €	3,06 €	3,06 €
Wimax cost per subscriber	10,32 €	10,32 €	10,32 €
Fibre network cost per subscriber	34,44 €	80,61 €	165,47 €
Total cost per passing	297,81 €	343,99 €	428,85 €

Service S2

	S2:25% configuration		
Subscriber equipment	Downtown Cost	Urban Cost	Rural Cost
CPE Indoor	250,00 €	250,00 €	250,00 €
Head End cost per subscriber	21,82 €	21,82 €	21,82 €
Wimax cost per subscriber	158,24 €	158,24 €	158,24 €
Fibre network cost per subscriber	68,87 €	161,22 €	330,94 €
Total cost per passing	498,93 €	591,28 €	761,00 €

	S2:50% configuration		
Subscriber equipment	Downtown Cost	Urban Cost	Rural Cost
CPE Indoor	250,00 €	250,00 €	250,00 €
Head End cost per subscriber	21,38 €	21,38 €	21,38 €
Wimax cost per subscriber	79,12 €	79,12 €	79,12 €
Fibre network cost per subscriber	34,44 €	80,61 €	165,47 €
Total cost per passing	384,94 €	431,11 €	515,97 €

Service S3

	S3:25% configuration		
Subscriber equipment	Downtown Cost	Urban Cost	Rural Cost
CPE Indoor	250,00 €	250,00 €	250,00 €
Head End cost per subscriber	53,24 €	53,24 €	53,24 €
Wimax cost per subscriber	395,60 €	395,60 €	395,60 €
Fibre network cost per subscriber	68,87 €	161,22 €	330,94 €
Total cost per passing	767,71 €	860,06 €	1 029,77 €

	S3:50% configuration		
Subscriber equipment	Downtown Cost	Urban Cost	Rural Cost
CPE Indoor	250,00 €	250,00 €	250,00 €
Head End cost per subscriber	53,24 €	53,24 €	53,24 €
Wimax cost per subscriber	197,80 €	197,80 €	197,80 €
Fibre network cost per subscriber	34,44 €	80,61 €	165,47 €
Total cost per passing	535,47 €	581,65 €	666,50 €

Service S4

	S4:25% configuration		
Subscriber equipment	Downtown Cost	Urban Cost	Rural Cost
CPE Indoor	250,00 €	250,00 €	250,00 €
Head End cost per subscriber	53,24 €	53,24 €	53,24 €
Wimax cost per subscriber	2 151,72 €	2 151,72 €	2 151,72 €
Fibre network cost per subscriber	68,87 €	161,22 €	330,94 €
Total cost per passing	2 523,83 €	2 616,18 €	2 785,89 €

	S4:50% configuration		
Subscriber equipment	Downtown Cost	Urban Cost	Rural Cost
CPE Indoor	250,00 €	250,00 €	250,00 €
Head End cost per subscriber	52,80 €	52,80 €	52,80 €
Wimax cost per subscriber	1 075,86 €	1 075,86 €	1 075,86 €
Fibre network cost per subscriber	34,44 €	80,61 €	165,47 €
Total cost per passing	1 413,09 €	1 459,27 €	1 544,12 €