ICT-215282 STP ROCKET

Reconfigurable **O**FDMA-based **C**ooperative Networ**K**s **E**nabled by Agile Spec**T**rum Use

D15

1d5 - Report on Business Models

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Abstract:

This deliverable is the result of 1A4 task of ROCKET project. It presents and describes business models and estimations about costs associated with the deployment, operation and maintenance of an OFDM-based 4G system in the 2.6 GHz band. Two deployment cases are considered: aggregated secondary spectrum usage (associated to WP2 activities) and relay-based deployment (associated to WP3 activities). A market analysis is included, as well as a description of the operational scenarios and system characteristics, including bandwidth allocation, antennas configuration, relay densities and relaying protocols. The results show the cost analysis and conditions required to obtain financial benefits from the ROCKET architectures. Conclusions are also derived about the radiated power of relay-based wireless communications systems.

Keyword list: Business cases, secondary spectrum trading, relay-assisted wireless systems, radiated power

EXECUTIVE SUMMARY

The different business cases presented in this deliverable have the purpose of modeling and evaluating the cost structure and economic feasibility of a ROCKET-based access network solution in a specific operator environment. More precisely, a new operator entrant on the European mobile communication market providing ubiquitous voice and broadband data services using the harmonized spectrum in the 2.6 GHz band is considered as the base case.

First, a business case based on a non-relay network is built. The objective of this base case is to provide an initial approach to business evaluation, taking into consideration the various costs associated with the deployment, operation and maintenance of the system.

The results obtained in the base case show that the main CAPEX contributors are related to the cell site installation and development, the base station equipment and the backhaul. The investment to acquire the spectrum license is relevant at the beginning, its importance falling up to 2% of total investment after ten years. In the case of OPEX, the main contributors are site rental, backhaul lease and maintenance and subscriber acquisition and retention costs (mainly related with the user terminal subsidy policy).

Then, a multivariable sensitivity analysis based on a Monte Carlo simulation is carried out. The variables that have a bigger impact on the profitability of the business case are those related to revenues (ARPUs and market shares), the cost of each mobile user terminal (*smartphones*) and the percentage of sites co-ubicated in sites used by other technologies. This site co-ubication can be made through a voluntary sharing arrangement among the operators or as a consequence of a compulsory regulatory measure taken by national regulatory authorities. The adoption of this measure could be an interesting way of reducing the entrant cost of new operators encouraging the infrastructure-based competition and it has been considered in several countries.

The impact of the total bandwidth available for the operator and the geotypes in the profitability of the business are then considered. Only in the case of 15MHz or 20MHz per sector (which corresponds to a total of 45MHz or 60MHz in the 2.6GHz frequency band respectively) the base case is profitable. As a consequence, in the case of using the channelisation proposed by CE, all the 50MHz for TDD technology should be assigned to one operator in order to guarantee the profitability of its business case.

Regarding the economic return achieved in the different geotypes, the results seem to confirm the idea that the provision of mobile broadband services in rural areas has to be based in lower frequency bands, such as 900 MHz after the refarming of this band is concluded and the 800MHz frequency band resulting from digital dividend. However, the ROCKET technology in the 2.6GHz can be used for different operators (such as cable or alternative operators that provide broadband services based in the access to incumbent networks) to provide mobile communication services in urban areas as a consequence of their needs to respond to fixed-mobile convergence.

The analysis focuses then on two other scenarios related to the two main technologies studied in ROCKET: spectrum usage and relaying transmission.

In order to estimate the prices of the possible spectrum transactions between operators in a secondary spectrum market, a simple model considering different spectrum assignment and geographic areas and a method are proposed, according to which, the largest number of potential transactions involves a new entrant as a seller/lessee and an incumbent operator as a buyer/lessor. In general, the largest beneficiary of radio spectrum in the secondary market is the incumbent operator due to the cost saving associated with the access to a larger amount of spectrum per sector. Similarly, the new entrant is a leading candidate to give up spectrum. The spectrum available and the zone of the deployment make also a difference with regard to the most likely transactions. In urban and suburban areas, the largest cost savings occur when the operator with less spectrum buys/leases spectrum.

Relay-based ROCKET architectures present better economic returns than non-relay based architectures, achieving positive EBITDA and free cash flows one year in advance, and increasing the positive difference with time. The higher number of antennas of the terminals improves economic results in any case. ROCKET and FIREWORKS project relaying protocols obtain similar economic results in terms of EBITDA, free cash flow and NPV, FIREWORKS slightly outperforming ROCKET.

Finally, relay networks seem to have a lower environmental impact due to a smaller radiated power, although conclusions about network enery consumption need further studies.

DISCLAIMER

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List of abbreviations & symbols

AP	Access Point
ARPU	Average Revenue Per User
BS	Base Station
BTA	Basic Trading Area
BWA	Broadband Wireless Access
CF	Costs of Fund
CIR	Committed Information Rate
CMT	Comisión del Mercado de las Telecomunicaciones
CSI	Channel Side Information
DSA	Dynamic Spectrum Access
DSL	Digital Subscriber Line
DSLAM	Digital Subscriber Line Access Multiplexer
EBITDA	Earnings Before Interest, Taxes, Depreciation and Amortization
EC	European Commission
HSPA	High-Speed Packet Access
IEEE	Institute of Electrical and Electronics Engineers
ITU	International Telecommunication Union
IU	Indoor Unit
LOS	Line Of Sight
MIMO	Multiple In Multiple Out
MNO	Mobile Network Operator
MS	Mobile Station
NLOS	Non Line Of Sight
OU	Outdoor Unit
PIR	Peak Information Rate
PMCIA	Personal Computer Memory Card International Association
RS	Relay Station
SME	Small Medium Enterprise
TDD	Time Division Duplex
VoD	Video on Demand
VoIP	Voice over Internet Protocol
3G	Third Generation

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1 INTRODUCTION

As wireless communications continue their explosive growth and diffusion within all spheres of industry and private lives, the problem of scarcity of suitable radio spectrum resources becomes ever more pressing. Recent history shows us several examples when large amounts of money had been paid by operators for securing access to moderate portions of spectrum in internationally harmonized mobility bands. At the same time, it is a commonly acknowledged fact that spectrum scarcity is not a physical phenomenon but rather an effect of inherent inefficiencies of current spectrum assignment practices. The traditional command-and-control school of spectrum management provides for orderly use of spectral resource and avoidance of interference through permanent and exclusive allocation of large portions of spectrum to monopolistic or oligopolistic sets of spectrum users. As a result, the spectral resource is often hoarded and used rather uneconomically by incumbent users, very much limiting opportunities for spectrum access by new users. Moves towards the use of market based policies for spectrum management, such as those advocated by the EC, provide a partial solution to these problems by giving users financial incentives to use spectrum more efficiently. However, these policies are built on the historic framework of spectrum access rights.

1.1 Function and purpose of the business case

The objective of this business case is to provide an initial approach to business evaluation, taking into consideration the various costs associated with the deployment, operation and maintenance of the system. These initial estimations will be reinforced alongside with the progress of the project, with the incorporation of the final specifications of the system as well as the results obtained from the various project activities (simulations and prototyping). This activity will take into account the operational scenarios, and will deploy the business models according to the target users, low and high populated areas, bandwidth, etc.

One of the fundamental scarce resources in communications and networking is the radio spectrum. Limited in state, scope and response mechanisms, network elements consisting of nodes, protocol layers and policies have been unable to make intelligent decisions and use the available spectrum efficiently. Extensive research in the field of spectrum management and utilization has led to the development of Dynamic Spectrum Access (DSA) techniques which will allow efficient usage of this spectrum.

There are two main technologies studied in ROCKET: spectrum usage and relaying transmission. In spectrum usage ROCKET has studied how to increase the usable spectrum through assignments and how to access the increased spectrum dynamically. In ROCKET, relaying transmission is used to improve spectral efficiency.

In order to assess the impact of ROCKET project, this document is focused in accomplishing two main objectives:

- Constructing a valuation model that will either assist the primary users to price the spectrum for secondary usage if the capital expenditure can be estimated with confidence OR helping finding an upper limit on the capital expenditure allowable in order for the firms providing this technology to be profitable, if the cash flows can be estimated with confidence

- Evaluating the economic impact of different currently research ROCKET project.

1.1.1 Problem Statement

The aim in this document is to propose a business framework for implementing this new generation of networking technology.

It is specifically interested to analyze the practical feasibility of ROCKET Systems in the real world. It is attempted to answer the following questions:

- What are the different functional models of ROCKET project that a firm can consider?
- Can we provide a framework for analyzing the business decision on the use of the technologies?
- How can we measure the maximum initial investment outlay that can be incurred by companies who implement these technologies and still profit from them?

1.2 Business cases in other projects

Various European projects that deal with next generation Wireless Broadband Networks have conducted deployment cost analysis; we pay special attention to IST WINNER II, IST ROMANTIK and IST- FIREWORKS projects. All evaluate the economical profitability of deploying new wireless technologies similar to those investigated in ROCKET.

1.2.1 The ROMANTIK business case for hybrid base-relay deployment

In [21], a hybrid deployment of macro BS and fixed RSs is considered. The approach considers a real map of an urban deployment, in which candidate sites for BSs and RSs are identified. In particular, the RSs can be located on lamp posts, which lead to a large number of possible locations. An optimization procedure is run for each scenario, which finds the best locations for BSs and RSs.

On the financial aspects ROMANTIK analyzes the potential cost/performance benefits of a mixed network configuration comprising base stations and intelligently deployed relay units. The cost model used in the optimisation process considered the most important costs associated with the deployment of a network viz., the site acquisition cost, the deployment costs, the maintenance costs and the cost of the equipment.

The ROMANTIK study investigates two scenarios; scenario 1 based on the Single Reduction in the Number of Base stations, and scenario 2 based on the Recursive Reduction in the Number of Base stations. The conclusion drawn is that the deployment of relays becomes economically attractive when the cost of a RS represents less than 75% of the cost of a BS on scenario 1, and less than 35% of the cost of a BS on scenario 2.

1.2.2 The WINNER business case for hybrid base-relay deployment

The system concept developed and investigated in WINNER II targets to provide ubiquitous broadband radio coverage in a cost efficient manner. To fulfil this objective Layer 2 relaying was identified as a potential solution to distribute the very high capacity of a broadband radio access point cost efficiently and flexibly. The second goal is to prove that such a solution is more cost efficient than other potential single hop deployment concepts.

The available public data of WINNER project only provides an example of the costs of macro BS and RS to implement WINNER architecture. The official data of WINNER deployment is not available in a public deliverable. In this way, costs of ROMANTIK and WINNER are not similar, for example for a macro BS ROMANTIK consider 120.000€ and WINNER 50.000€, and site acquisition and deployment costs in ROMANTIK 30.000€ and in WINNER 60.000€. This seems reasonable since the projects ran in different periods; ROMANTIK was carried out earlier than WINNER, so the technology could be more expensive and the site cheaper.

1.2.3 The FIREWORKS business case for relay OFDMA wireless architecture

The objective of FIREWORKS is to design and validate a prototype of the next generation Broadband Wireless Access (BWA) systems based on IEEE 802.16e and 802.11s Standards.

Business Case of FIREWORKS shows that relays are profitable if the cost ratio BS/RS is higher than three. Relays benefits change in relationship with the throughput density, number of antennas and protocol used, however simulation indicates that a BS/RS cost ratio equals to five provide benefits in most situations.

The business case results show also that a network based on FIREWORKS architecture can provide a positive cash flow and EBITDA in few years.

2 SCENARIOS DEFINITION

This section defines the variables related to the project in order to exactly define the basic scenario for the business case. The scenario used to realize the business case includes different applications and coverage areas.

2.1 Introduction

The selection of the reference scenario is very important in the realization of the business case. In this document a realistic scenario for the European market usable in short and medium terms (up to ten years) is considered. Particularly, the business case will be carried out for the provision of ubiquitous voice and broadband data services using the harmonized spectrum in the 2.6 GHz band (see section 5.2).

2.2 Market segments

In this business case, the following market segments are considered:

- **Mobile communication services.** The mobile communication market has been one of the more growing communication markets in the world since its emergence in the last decade. Despite the trend to saturation as a consequence of the high penetration level that has already been reached in most European countries and the lower growth rate[1] in voice service revenues as a result of the increasing competitive and regulatory pressure on operators to reduce their voice prices, the emergence of the Mobile Internet provides new opportunities to operators using emerging technologies such as the ones studied in ROCKET project.

  In fact, usage of broadband data services via mobile handsets is increasing very much lately, largely as a result of growing 3G handset penetration and the introduction of affordable unlimited data bundles. Improvements to mobile browsers, better content adaptation, more mobile-friendly content and MNOs' abandonment of the 'walled garden' approach have also improved the browsing experience for mobile users.

  As a result, the adoption of wireless ROCKET architecture can be therefore used to increase competition and services provision to the users in a market typically controlled by the mobile operators.

- **Mobile broadband access.** The emergence of next generation mobile networks as a consequence of the evolution of 2G and 3G cellular networks and other metropolitan access networks provides a new alternative for the Internet broadband access. Besides, these new technologies provide a differential characteristic as a consequence of the ubiquitous access that they offer to their customers.

  The mobile broadband market has had an unprecedented increase as a consequence of different factors such as:

  - The deployment of HSPA in 2006 and 2007 enabled Mobile Network Operators (MNOs) to provide data rates (nominally 3.6Mbit/s, but more realistically 1Mbit/s) that could deliver an acceptable browsing experience and compete with fixed broadband.

[1] According to Analysys Research [2] voice services will show a compound annual growth rate (CAGR) of 2.3% in the period of 2006-2012

- The arrival of USB dongles in September 2007 provided a more user-friendly experience than PCMCIA cards.
- A strong marketing push, led initially by 3G mobile operator entrants, increased consumer awareness, and a reduction in average subscription prices encouraged take-up.

Moreover, wireless broadband access will play a key role in the growing political interest in bringing "broadband to all" policies, first because its cost effectiveness may exceed that of wired broadband, especially where population densities become low and second because of the distinct value offered by mobility and wireless connectivity in general.

As a consequence, the emerging mobile broadband market offers a true opportunity for operators using wireless ROCKET architecture as it will be showed in the following sections.

Additionally, two different groups of customers can be considered in both markets: **business and residential customers.** Despite certain differences can be founded between these two kinds of customers in term of services consumption and ARPU, mean market values are going to be considered for both markets. Other markets could affect ROCKET network but will not be considered to not make the business case more abstract. These include:

- **Cellular Backhaul:** The use of point-to-point microwave is more prevalent for mobile backhaul, but ROCKET can still play a role in enabling mobile operators to cost-effectively increase backhaul capacity using ROCKET technology as an overlay network. This overlay approach will enable mobile operators to add the capacity required to support the wide range of new mobile services they plan to offer without the risk of disrupting existing services

- **WiFi Hot Spot Backhaul**: WiFi hot spots are being installed worldwide at a rapid pace. One of the obstacles for continued hot spot growth, however, is the availability of high capacity, cost-effective backhaul solutions. This application can also be addressed with the ROCKET technology. With nomadic capability, ROCKET can also fill in the coverage gaps between WiFi hot spot coverage areas

2.3 Deployment scenarios

The set of deployment scenarios considered in the business cases are the ones considered in the ROCKET project [25] and are detailed below:

- **Urban scenario:** In this case we have a huge number of potential customers, all SME and high enterprises, people of residential zones and mobile users. ROCKET architecture can provide users and enterprises a ubiquitous wireless solution that will satisfy their broadband requirements, avoiding actual needs of cable access to have broadband services. These services could be delivered for fixed and mobile users, and they are the conventional ones as defined in ITU and IEEE: background, interactive, streaming and conversational.

  Main characteristics of urban scenario are:
  - Highest density of potential broadband customers
  - Many multiple tenant office and residential buildings
  - Smaller cell sizes to meet capacity requirements

- Strong competition: Drive by market size and availability of alternate access technologies
- Due to the competitive environment a new operator can expect: lower market penetration and higher marketing and sales expense
- Licensed spectrum would be desirable to minimize potential for interference

Urban areas have little available spectrum at any range. This kind of scenario is defined by a high density of traffic, so the system can operate using short-range access points (APs) and have large reuse. The technologies studied in ROCKET about the efficient use of spectrum are very important to support all transmissions requests and to avoid system congestion.

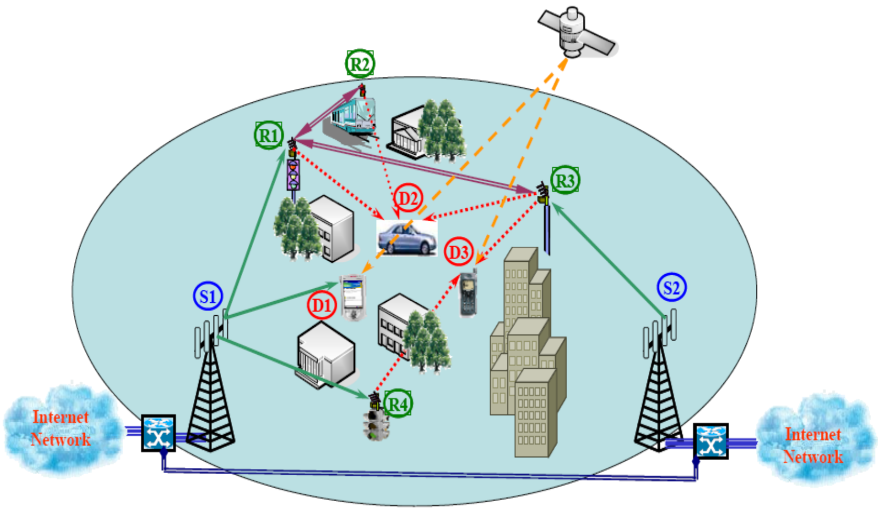

Figure 1. Urban scenario, according to [12]

- **Suburban scenario**: Suburban areas are commonly defined as residential areas on the outskirts of a city or large town. These areas have a medium population density. Potential customers are lower than for the urban case, but usually competition is not that high. In some suburban areas, cable or xDSL could not be available or provided only by the local servicing telecom operator.

- **Rural scenario:** In this scenario we will deploy a fixed relay network in order to provide high bit rate connectivity to sparsely populated areas.

  Main characteristics of rural scenario are:
  - Distant from major Metro Areas
  - Residential and small business
  - Very little, if any, cable or DSL
  - High pent-up demand for internet access
  - Limited competition
  - New operator can expect very high market penetration and rapid adoption rate
  - High capacity backhaul may be a challenge
  - The available spectrum is greater than in urban areas
  - APs need to use longer ranges to efficiently cover the sparse customers
  - Rural areas require long range communication which requires spectrum to be available over large areas

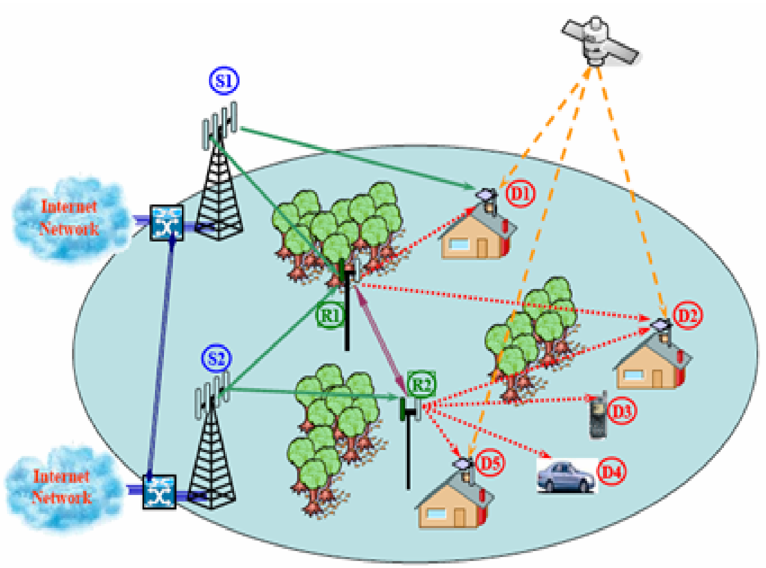

Figure 2. Rural scenario, according to [12]

2.4 Demographics

Demographics are an important consideration to define the business case. It is unique for each country; in ROCKET we assume the same demographics considered in FIREWORKS project, the Italian market demographics [19]. The country is divided into urban, suburban and rural areas according to the deployment scenarios defined above.
Urban areas are characterized by a high population density, typically more than 1000 persons per square kilometre. These areas have the highest density of potential customers and higher competition. Therefore, in these areas the operators should plan coverage based on small cell size (high density customers). It is usually very difficult to reach a high customer penetration because there are usually many operators offering a high variety of services.

Suburban areas are commonly defined as residential areas on the outskirts of a city or large town. These areas have a medium population density. Potential customers are lower than for the urban case, but usually competition is not very high. In some suburban areas, cable or xDSL could not be available or provided only by the local servicing telecom operator.

Rural areas are settled places outside towns and cities, and also include small cities located far from any metropolitan area. The customer density is usually low but within small cities can be fairly high. In these areas, cable or xDSL broadband accesses are typically unavailable.

Geotypes	Area (km^2)	Area share (%)	Total population	Population share	Employees
Urban	1,952	0,6%	11,128,285	19,4%	4,263,708
Suburban	16,433	5,5%	15,605,546	27,2%	6,180,072
Rural	282,412	93,9%	30,587,239	53,4%	11,610,228
Total	**300,798**	**100%**	**57,321,070**	**100%**	**22,054,008**

Table 1 Reference market for the business case [16]

The business case will use as target users the population and the business users considered. Table 1 shows how the whole country is divided among the different geotypes. A yearly population increase of 1% is also considered.

3 DEFINITION OF THE ROCKET SYSTEMS

In this section the characteristics and options of the ROCKET network, that could have an impact on realizing the business case, are specified and defined. The results produced by others WPs are taken into account in the definition of the system.

3.1 Deployment-related features

- **Channelization**

Several channelization options are possible in IEEE 802.16m: 5MHz, 7MHz, 8.75MHz, 10MHz and 20 MHz although WiMAX profiles are currently defined only up to 10MHz.

- **Backhauling**

Backhaul of ROCKET BSs can be a wired link of optical fibre or a microwave dedicated link (especially in rural areas)

- **BSs and RSs sites**

In urban areas macro BS may be mounted on towers on top of buildings, micro BSs are typically mounted on rooftops and RSs can be either mounted on rooftops or on lamp-posts. In rural areas, macro BSs are mounted on towers and it is likely that RSs will also be mounted on towers in order to provide a sufficient coverage extension. It is assumed that RS are placed in such a way that propagation to the serving BS is LOS, while propagation to other cells BS is NLOS.

- **Relay usage**

The use of RS provides a balance between enhanced cell coverage and enhanced throughput which is different depending on the propagating conditions and the relay deployment. Depending on the nature of the relay, the most relevant usage scenarios are:

  - Fixed RS to provide coverage to areas beyond the cell edge, in two or more hops. Relay stations are placed in over-the-roof positions so that a good quality link to the BS is provided
  - Fixed RS for multihop relaying in rural areas. Relay stations are placed in over-the-roof positions so that a good quality link to the BS is provided
  - Fixed RS to improve per user throughput in areas not sufficiently covered, due to shadowing, indoor or underground coverage. Relay stations are placed in over-the-roof positions so that a good quality link to the BS is provided.
  - Nomadic RS (portable but static when operating), can be used where portable RS can provide access to subscribers within a room or a building. Relay stations are placed in LOS or NLOS conditions to the BS
  - Nomadic RS to provide temporary coverage to areas where the traffic experiences a peak, in emergency situations or for disaster recovery if infrastructure is defaulting. Relay stations maybe placed in LOS or NLOS positions, depending on the availability of sites
  - Mobile RS can be mounted on a vehicle and connected to the BS through a radio link. The RS provides improved access

For the business case studied here, the scenarios tested correspond to the 2nd and 3rd bullets. In each case the owner of the relay terminal may be the customer or the infrastructure provider. However, our study assumes that it is the operator who does the full investment.

- **Features that condition the design**

The presence of a relay modifies profoundly the concept of source-destination communication. The coordination between source, relay and destination opens a high number of possibilities in the definition of the relay-based transmission system. A number of features that condition the design are:

  - **CSI availability**. Average SNR is assumed known on each link.
  - **MIMO terminals**. 1 or 2 antennas are assumed for BS, RS and MS
  - **Duplexing mode of the relays: half-duplex and full-duplex**. Different protocols for half-duplex relaying have been tested, according to the most promising techniques described in WP3 [27]: forwarding, Protocol III and TWRC. The full-duplex mode has been assumed for a deployment of AF relays.
  - **Single RS or multiple RS assisted transmission**. It is assumed that each MS is served by a single RS.
  - **One-directional or Two-directional protocols**: forwarding and Protocol III for the former case, while TWRC for the later.
  - **Orthogonal access or superposition coding**. TDMA is assumed for user access.
  - **Scheduling policy**. It is assumed that the same rate is given to all users in the cell.
  - **RS operation: AF, DF, CF**. AF is used for full-duplex relaying and DF for all other relaying protocols.
  - **Retransmission policies**. No retransmissions are assumed.
  - **Fixed or adaptive allocation of resources**. The transmission time in the BS-RS and the RS-MS links is optimized depending on the quality of the links for maximum transmission rate.

- **Cell size**

Cell sizes are optimized according to both spectral efficiency and outage. Urban environment is capacity-limited while the rural environment is coverage-limited. Typically ranges are from a few hundred meters for an urban microcell to several kilometers for a rural macrocell. The cell size has a direct impact on the propagation channel, for example, a larger cell means a larger delay spread.

- **Frequency planning and cell clustering**

The cell shape is defined as a hexagon. In order to reduce interference and not to affect excessively the trunking gain, three sectors of 120º will be defined per cell. Therefore different approaches for frequency planning can be taken:

  - 1/3/1: One band allocated to all cells, 3 sectors per cell, same band for all sectors
  - 1/3/3: One band allocated to all cells, 3 sectors per cell, the band is split into three and each subband is allocated to different sectors
  - 3/3/1: The band is split into three and allocated to clusters of three neighbour cells, 3 sectors per cell, all sectors in a cell use the same band

The frequency planning studied here corresponds to a 1/3/3 deployment.

3.2 Device characteristics

Main device characteristics are defined in [26]:

- **BS characteristics**
  - Two parts: OU (Outdoor Unit) responsible of radio transmission and IU (Indoor Unit) installed inside the building that hosts the Base Station
  - OU should not exceed 1 m^3 and should not weight more than 25kg. Similarly, the size of the IU should be less than half of the OU's and its weight limited to 20kg
  - BS must be composed of 3 sectors
  - For each sector has a minimum of 2 antennas, with antenna spacing over 4 times the signal wavelength (4λ). 2 antennas are used in our study.
  - BS operates at 2.6 GHz or 3.5GHz.
  - The range of the DC Voltage is -48/60 V according to ETS 301132-2.
  - The range of the transmitted power per sector goes from 33dBm to 40dBm. Our simulation setup assumes 40dBm.
  - It is recommended that antenna gains be 13-17 dBi
  - Power consumption should not exceed 50W and 30W for the outdoor and indoor units respectively
  - The interconnection of outdoor and indoor units should be made through a coaxial cable no longer than 100m

- **RS characteristics**
  - For fixed RSs in rural areas, transmit powers can be consider similar to those of macro-BSs (40dBm). The system evaluation done here assumes 30dBm in rural, suburban and urban scenarios.
  - For mobile RSs onboard a public transportation or public safety vehicle, transmit power cannot be higher than 1dBm.
  - RS may be sectorized and equipped with multiple antennas. 2 omnidirectional antennas have been used.

- **MS characteristics**
  - Maximum transmit power of 23 dBm
  - Single or dual antenna are considered.

3.3 ROCKET technology differentiators

The PHY/MAC techniques investigated in ROCKET project that can improve deployment costs are listed below, only the 2nd and 3rd have been included in the business case:

- Dynamically increased usable spectrum by opportunistic spectrum usage and coexistence
- Increased usable spectrum by assignment
- Single-user cooperative techniques
- Multi-user single-cell cooperative techniques
- Multi-BS and RS cooperative transmission techniques
- Multi-cell Advanced Antenna Techniques for Coordinated BSs and RSs
- Multi-cell Radio Resource Management for Coordinated BSs and RS
- Design of an ultra-efficient MAC protocol
- Design of a reconfigurable air interface

4 MARKET ANALYSIS

4.1 Market Trends

The current trend in the telecommunication industry is driven by the vision of Seamless Mobility involving users having easy, uninterrupted access to information, entertainment, communication, monitoring and control. Advanced technology can be used to drive this paradigm shift, including: Intelligent Interaction, Content Handling, Real-Time Communications, Sensing & Control, Heterogeneous Networks, Session Continuity, Security, and Manageability. Note that ROCKET deals with many of these enablers.

4.1.1 Market Adoption Rate

It generally takes a period of time for consumers to "buy-in" to a new technology, a new service or a new provider of that service. For some consumers the technology, service and/or provider have to be well-tested before they will sign up for the service. Mobile phones and more recently, WiFi (IEEE 802.11) has helped to establish a general acceptance of wireless access so it is reasonable to expect that Wireless technology will have a fairly rapid adoption rate. The rates charged for services by the operator will also have a marked effect on how quickly the technology and services will be adopted and regions that are currently underserved will have a quicker adoption rate than areas that are currently well served. Figure 3 shows the market adoption rate[2] to reach 90% of the expected mature market penetration for a 3, 4 and 5 year adoption curve respectively.

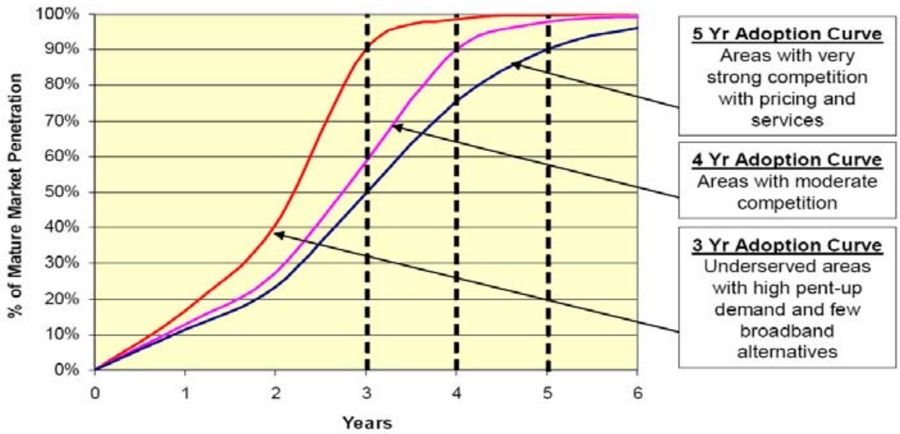

Figure 3. Market Adoption Rates for Business Case Analysis

4.1.2 Drivers and Inhibitors

The telecommunication market is currently driven by supplies (technologies) and demands (people, market opportunities), whereas some drivers are to be carefully considered. They can be listed as below:

- Technologies: explosion of information bits (loads of data everywhere with ever increasing file size), IP-zation of the information (explosion of VoIP that may progressively replace voice transfer), explosion of smart and low cost nodes (Wi-Fi AP, laptops, handsets, PDAs, notebooks, music players…) and rapid technology adoption

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2 The expected adoption rate curve will roughly follow the shape defined by the Rogers Innovation Adoption Curve. For more information see www.valuebasedmanagement.net

- Government initiatives to reduce the digital divide are making gains for broadband wireless
- As individuals, businesses and communities demand broadband access anytime and anywhere, the need for high-speed grows
- Growth in broadband wireless network backhaul
- Consumer value-added services that operators can offer to differentiate services over broadband wireless networks include home networking, music downloads, online gaming, video on demand (VoD) and voice over IP (VoIP)

Inhibitors: loss of privacy, device complexity, uncertain business models (risk taking on wide range of available emerging technologies), finite resources.

4.1.3 Broadband Wireless Value Chain

The broadband value chain encompasses everything from the services delivered via broadband to the installation and maintenance systems needed to support broadband access and such services.

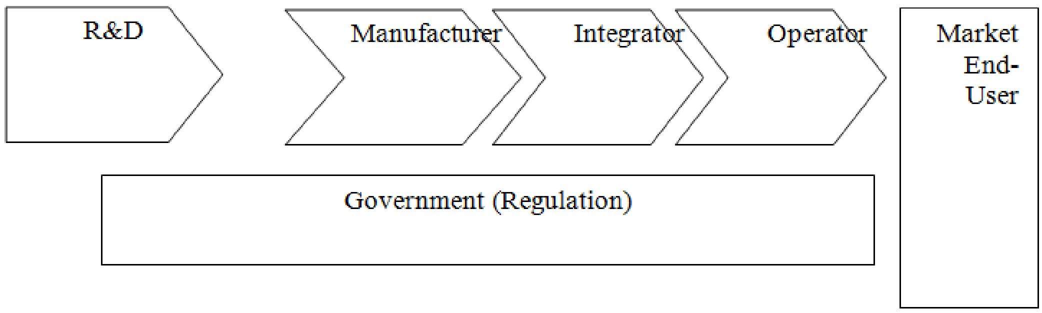

Figure 4 BroadBand Wireless value Chain

In ROCKET several agents (R&D centers, manufacturers, Integrators, operators) are acting together sharing their knowledge in order to get a new product.

4.1.3.1 Actors

We first make an identification of key entities (actors), their interaction with each other (relationships) and the value adding activity (role) they provide in the marketplace.

1) *Spectrum brokers:* Two types of market makers might come into the picture for spectrum trading.
    - Primary brokers: Responsible for distribution of new spectrum initially according to FCC specifications. The spectrum can be distributed using the auction approach in which the availability of spectrum for usage is initially advertised. Then the interested parties submit their tender offers. The highest bidding offer is awarded the spectrum for usage.
    - Secondary brokers: Responsible for trading spectrum for secondary usage. The main function of these brokers will be to match the excess spectrum availability of the primary users with the spectrum needs of the secondary users. These brokers can maintain a database (similar to a book maintained in financial markets) wherein the white spaces (spectrum) available at any point in time are recorded.

2) *Network Transport:* The network operators are responsible for the set-up and installation of the wireless network and integrate the entire operating chain, consisting of spectrum

brokerage, mobile network transport and mobile service provisioning. The operation and maintenance of the network can be carried out either at the local level or by a centralized entity. The implications of these two alternative approaches will be observed at the functional and the financial model levels.

3) *Network equipment provider / Middleware Vendors:* They will be responsible for the distribution of initial hardware to the network transport provider for initial implementation of the network. They will be lower in the hierarchy to the Network Transport provider.

4) *Application developers / Integrators / Operators:* Responsible for development of applications useful for utilizing the network functionality as well as system operation and integration.

5) *Content Providers / Aggregators / WISP:* These entities include those providing data services (text, music, video, etc.) as well as advertising entities.

6) *Customer-facing Entities:* They bundle all services for the end-user including technical support, content provisioning, Internet access, end-user hardware and software solutions as well as billing services.

7) *End Users / Licensees:* Two types of end users: Primary Users and Secondary Users. The Primary User entity is a conceptual entity referring to the primary licensee of the spectrum. This could be the user, the customer facing entity, the Network Transport or anyone else who currently holds the spectrum rights on a long term basis. Primary users will utilize the spectrum allocated initially in the primary markets. They can be military and defense organizations, corporations, industrial manufacturers and even households. The class of secondary users may include organizations not needing spectrum usage on a regular basis or can be one of the primary users needing extra capacity during overloads or for large bandwidth application requirements.

8) Regulatory authority: The Regulatory Domain includes regulation and spectrum management authorities. The Regulatory Entities set the legal environment for the Wireless business growing, that is, laws and guidelines that determine the operation of the whole system. This includes aspects such as the acceptable equipment behavior (regarding frequencies, power, etc.) and the tests that must be passed in order to place equipment to the market. The Spectrum Manager can be considered integrated within the Regulatory entities but this may change as reconfigurability allows for flexible and dynamic allocation of spectrum. This actor is responsible for approving and monitoring spectrum allocation to different entities and the transfer of spectrum between them. Many problems may arise due to the secondary usage of spectrum (e.g.: failure to release spectrum after the allocated time, interference to primary users by the unauthorised secondary users, etc). A standard will need to be developed which details the rules for transfer of spectrum rights temporarily from the primary user to the secondary users, spectrum usage restrictions (secondary user transmission power, time delimited secondary access, etc.) and penalties for any such violations. The regulatory body established will play a pivotal role to make sure that the contracts and standards are honoured.

4.2 SWOT Analysis

A SWOT analysis matrix should be interesting to show ROCKET project's Strength, Weakness, Opportunities and Threats. We provide two analysis corresponding to the two technologies studied in ROCKET: one for relay-based deployment, and another for the use of aggregate spectrum. This analysis will determine how the business plan of the global project will evolve.

4.2.1 Use of aggregate spectrum

Strengths	Weakness
• Enhanced spectrum efficiency, coverage range and reliability. • Efficient and effective response to regulatory bodies in various countries (e.g. Federal Communications Commission in the United States, and Ofcom in the United Kingdom), who found that most of the radio frequency spectrum was inefficiently utilized.	• As a new technology it is need that operators deploy the system in whole coverage area. • A high commercial and marketing campaign is needed in order to reach all possible customers.
Opportunities	**Threats**
• Spectrum trading gives the opportunity to incumbent, medium size or new operators to trade with unused spectrum and to optimize its network deployment strategy. • ROCKET will enable service providers to deliver QoS compliant Triple Play services to a wide range of enterprise and residential users, no matter whether they are located in urban or remote areas. • Companies providing spectrum trading platforms are required. • Increase the value of the companies. • The avoidance of steep installation costs, helping operators to overcome the digital divide.	• In urban areas there are several broadband services such as DSL or T1 established. • 3G systems could improve their throughput to provide a high range of services delivering QoS. • Next LTE technology.

Table 2. Use of aggregate spectrum

4.2.2 Relay-based deployment

Strengths	**Weakness**
• Wide coverage range in less time and lower CAPEX and OPEX. • Enabling technology to provide biquitous wireless solution to reach bit rates higher than 100 Mbps with peak throughputs higher than 1 Gbps, if efficiently combined with spectrum aggregation. • Homogeneous high rate coverage that guarantees constant user experience over the whole served area, and hence providing service differenciator.	• To increase the capacity of the network, relays should be replaced by BS after few years. • A high commercial and marketing campaign is needed in order to reach all possible operators. • Manufacturing or software update of BS, RS and MS devices • Network planning needs revision. • New sites for RS deployment are required.
Opportunities	**Threats**
• Relay deployments will enable service providers to deliver QoS-compliant Triple Play services to a wide range of enterprise and residential users, no matter whether they are located in urban or remote areas. • The system deployment cost is expected to be significantly less than any other wireless or wired broadband access system to date. • Increase the value of telecommunication companies. • Reduction in the cost of backhaul deployment due to the enlarged cell size. • New network planning tools are required. • In emerging countries, the main focus of broadband deployment is on urban and sub-urban areas, and will remain so in the near future. The low POTS penetration and the low quality of the copper pair prevent mass scale DSL deployment and foster the need for alternate wireless broadband technologies. • Choice for underserved rural and outlying areas with low population density: providing a wired broadband connection to a currently underserved area through cable or DSL is not suitable or a time-consuming, expensive process, with the result that a large number of areas in the world do not have access to broadband connectivity. • The avoidance of steep installation costs – no outside plant costs necessary for copper/fiber and the ability to quickly provision service, even in areas that are hard for wired infrastructure to reach, helping operators to overcome the digital divide	• In urban areas there are several broadband services such as DSL or T1 established, so the market for enhanced high speed mobile services might not take off. • New technologies might be incorporated in the future in 3G systems so that they can improve their throughput/coverage and providing a high range of services delivering QoS.

Table 3 Relay-based deployment

5 FREQUENCY ALLOCATION

5.1 Frequency Band Alternatives

A key decision with regard to spectrum choice is whether to use licensed or unlicensed spectrum. The use of licensed spectrum has the obvious advantage of providing protection against interference from other wireless operators. The disadvantage is dealing with the licensing process. This process varies depending on local regulations from either being very simple and quick to complex and lengthy; in countries where auctions are used, it can be expensive in highly sought-after regions. The use of unlicensed spectrum gives the wireless operator the advantage of being able to deploy immediately but runs the risk of interference from neighbouring wireless operators in the future.

In general the use of licensed spectrum could be desirable in major metropolitan areas where multiple wireless operators are more likely. License exempt spectrum on the other hand, could often be a good choice in rural areas where there are likely to be fewer operators. In these areas interference mitigation is easily accomplished through frequency coordination between the operators.

ITU-R studies showed that a considerable amount of spectrum is required to provide the total capacity required in the future and to meet the high data rate requirements imposed on the systems.

The possible additional bands for the IMT-Advanced are identified as:

- **790-862 MHz**: The 790-862 MHz "digital dividend" spectrum was identified at WRC'07 for IMT. It is interesting for ROCKET because its NLOS propagation characteristics should allow cost efficient deployment. Large cell radius can be achieved which is especially well suited for rural areas.

  The EU has worked to develop a common approach towards the digital dividend. Both the Council and European Parliament have called upon Member States to cooperate in achieving this harmonisation. The Radio Spectrum Committee issued mandates to CEPT to examine the technical considerations relating to the digital dividend, which have already resulted in three reports. CEPT working groups and project teams are also considering potential band plans for the 790-862MHz sub-band, as illustrated in Figure 5.

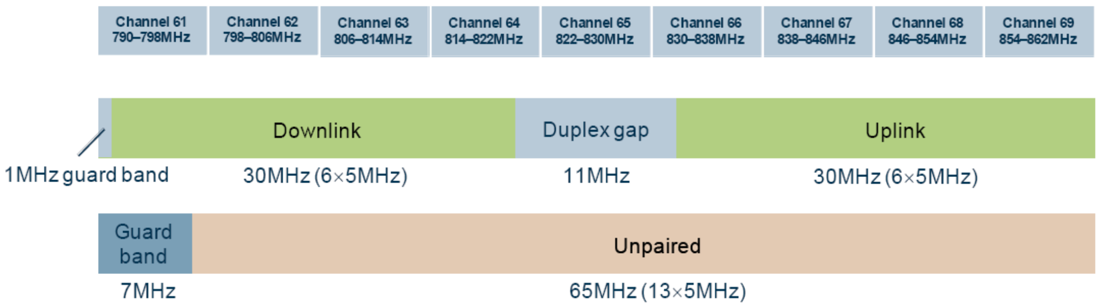

Figure 5. Draft harmonised channel arrangements for the 790-862MHz sub-band. Source: Analysys Mason from ECC PT1 [5]

Recently, the EC launched a consultation on Digital Dividend spectrum [12] followed by an EC Communication [13] and a EC Decision [14]. Noting the importance of taking prompt action "to prevent the emergence of fragmented national legacy situations" that would stymie the development of future equipment and services in the 800 MHz band, the consultation proposes that the EC undertake two urgent actions by autumn of 2009: (1) Member States that have not completed the digital switchover would be requested to confirm switch off of analogue TV under national law by 1 January 2012; and (2) the EC would draft a Commission decision, for regulatory opinion in the autumn of 2009 and formal adoption at the beginning of 2010, on technical harmonization measures for transitioning the 790-862 MHz band to non-broadcast uses. In its probable mobile configuration this spectrum will use 832-862MHz to send information from the mobile handset to the base station (uplink) and 793-823MHz for the other direction (downlink) as the proposed by CEPT in the last figure.

At the present time, many European countries such as Austria, the Czech Republic, Finland, France, Germany, Spain, Sweden, the Netherlands and the United Kingdom have begun to consider how to open the 800 MHz band for innovative uses such as mobile broadband.

- **2300-2400 MHz**: This spectrum was also identified globally at WRC 2007. Compared to the 3400-3600 MHz spectrum, it allows (like the 2500-2690 MHz band) a significant reduction of the number of BSs required to cover a given area.

- **2500-2690 MHz**: The 2.6GHz band has been the focus of much attention since it was identified as a future expansion band for mobile broadband services at the ITU World Radio Conference in 2000 and is currently being auctioned or planned to auction for TDD and FDD technologies (such as WiMax and LTE) in most European countries.

  Compared with the way previous licences for 3G were granted, this auctioning process is "technology-neutral". The band is typically split into blocks of paired and unpaired spectrum, which are particularly suitable for UMTS/LTE and mobile WiMAX technologies respectively. In fact, the EU's Decision on harmonisation of the use of the 2.6 GHz band [11] proposes for the operation of this band the use of two paired blocks of 2×70 MHz for operation in FDD mode plus one of 50 MHz for TDD operation.

  However, the European Commission did not specifically endorse any particular channel arrangement leaving freedom to the member countries to expand the spectrum devoted to TDD. Citing the European Decision 2008/477/EC the European Commission states the following -

  "A. GENERAL PARAMETERS
  1. The assigned blocks shall be in multiple of 5,0 MHz.

  2. Within the band 2 500–2 690 MHz, the duplex spacing for FDD operation shall be 120 MHz with terminal station transmission (up link) located in the lower part of the band starting at 2 500 MHz (extending to a maximum limit of 2 570 MHz) and base station transmission (down link) located in the upper part of the band starting at 2 620 MHz.

  3. The sub-band 2 570–2 620 MHz can be used by TDD or other usage modes complying with the BEMs in this Annex. Outside of the sub-band 2 570–2 620 MHz such usage can be decided at national level and shall be in equal parts in both the upper part of the band starting at 2 690 MHz (extending downwards) and the lower part of the band starting at 2 570 MHz (extending downwards)."

  As an example, the National Regulatory Authority of United Kingdom, Ofcom, has planned the award of this frequency band [23] in a way that it is for the market to determine how the band is used as between these two main types of use (paired and unpaired); it presents different results of channelling arrangements that could be presented after the auction (see Figure 6 and Figure 7). Arrows indicate how unpaired spectrum can increase over the minimum of 50MHz.

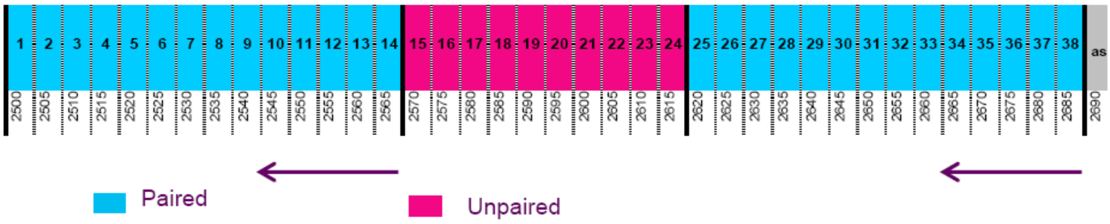

Figure 6. 2.6GHz band-plan proposed by Ofcom with labelling of blocks 1 to 38 showing paired and unpaired spectrum as per the CEPT band plan (Source: Ofcom [23])

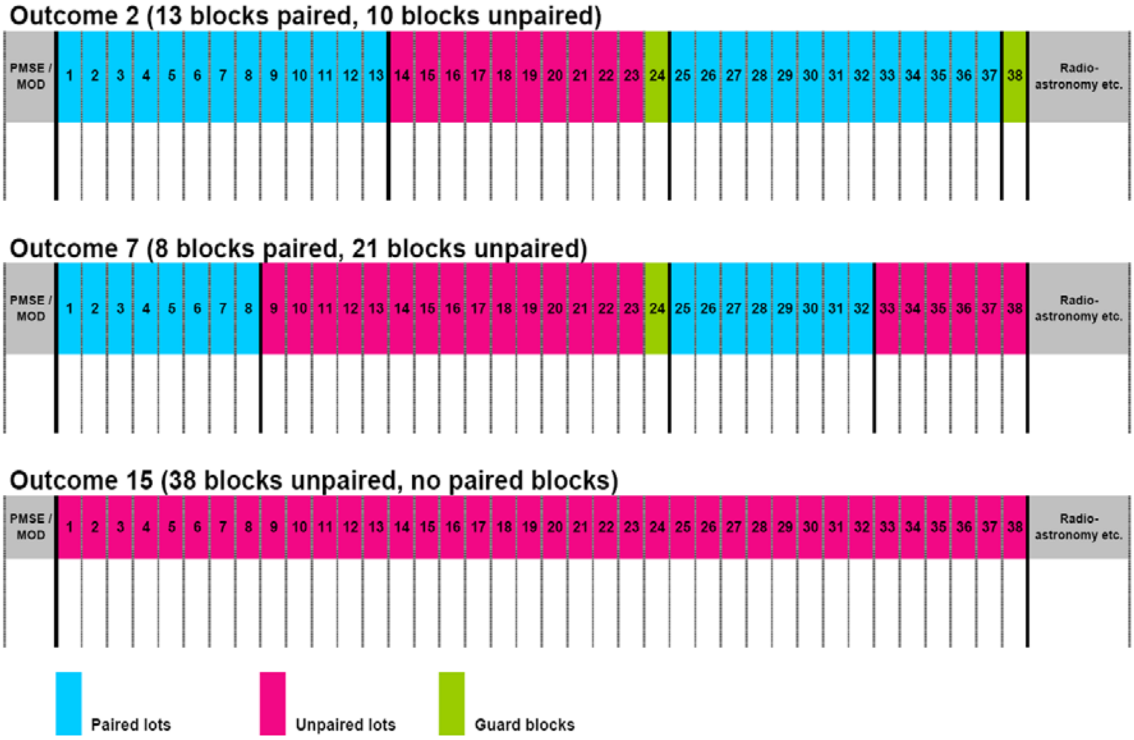

Figure 7. UK 2.6GHz Auction: TDD/FDD flexibility (Source: Ofcom [23])

However, so far European countries that have already auctioned this frequency band have used the channelling arrangement of two paired blocks of 2×70 MHz for operation in FDD mode plus one of 50 MHz for TDD operation (such as Finland and Sweden and with the exception of Norway, that reserves 70MHz for TDD operation) so this arrangement seems to be the most probably used in Europe.

Since 2007, four auctions have taken place in which 2.6GHz spectrum was awarded. One auction took place in Hong Kong and the other three in Europe (Norway, Sweden and Finland). Most other Western European countries are planning the award of 2.6GHz frequencies for either the second half of 2009 or for 2010. Table 4 provides a non-exhaustive list of planned auctions.

Country	Schedule	Country	Schedule
Austria	Either end of 2009 or end of 2010	**Norway**	Completed (November 2007)
Italy	Probably 2010	**Denmark**	2H 2009
Belgium	2009	**Poland**	2009, may be delayed by 6 months
Netherlands	1Q 2010	**Finland**	November 2009
Czech Republic	After 2012	**Portugal**	Undecided, consultation recently concluded
France	2010	**Slovenia**	2009
Germany	2H 2009	**Greece**	Undecided, consultation launched March 2009
Spain	Undecided, consultation recently launched	**Sweden**	Completed (May 2008)
Hungary	Band unusable due to NATO radars	**Ireland**	After 2012–2014
UK	3Q 2009, possible further delay		

Table 4.Non-exhaustive overview of timing and characteristics of European 2.6GHz spectrum auctions (Source: Analysys Mason [4], data as per April 2009)

- **3400-3600 MHz**: This spectrum was identified in many countries at WRC'07. Some WiMAX licenses have already been granted (e.g. for Fixed Broadband service in France) in this band.

5.2 ROCKET frequency band

ROCKET BSs operate at 2.6 or 3.5GHz frequency bands and are mainly TDD with channel bandwidth of 100 MHz and frame duration of 5 or 10 ms. BSs have to operate under specific regulations depending of the country.

In the calibration scenarios of ROCKET [25] 5, 10, 15 and 20 MHz bandwidth are proposed. Although ROCKET bandwidth could be a maximum of 100 MHz, a 15 MHz channelization with a reuse factor of 3 in the 2.6GHz frequency band is proposed in this business model. This channeling configuration is compatible which the one used in most of European countries (two paired blocks of 2×70 MHz for operation in FDD mode plus one of 50 MHz for TDD operation), which implies a total 45 MHz spectrum. 802.16e firstly chose the TDD mode and accordingly did the ROCKET consortium.

6 ROCKET BUSINESS CASE

This section presents the main assumptions made and results obtained in the business case. The methodology used is based on techno-economic modeling frequently used in many other European research project (TITAN, OPTIMUM, TERA, TONIC, ECOSYS and many other).

Techno-economic modeling is a simulation-based approach for developing and optimizing system solutions in different operator and business environments. It can be extended from basic cost modeling to business models to produce an extensive set of financial and technical results. It gives an opportunity to analyze the network cost structure and the effect of service penetrations and revenues on overall business feasibility. The importance of this type of modeling is being realized as the different players in the telecom sector have recognized the variety of cases and circumstances that can be modeled.

In this case, techno-economic modeling is used to stand for the modeling and evaluation of a ROCKET-based access network solution's economic feasibility in a specific operator environment (from section 6.1 to 6.6). More specifically, a new operator entrant in the European mobile communication market is going to be considered as our case base.

To deal with the risk associated with a possible variation in the value considered for the different assumptions, it is valuable to conduct a sensitivity analysis to get a view of the variability of the outcome and the overall risk of the project. A sensitivity analysis means studying how the variation in the output of the model can be apportioned to different sources of variation. It can be used to identify which variables contribute the most in the output's variability. In this project, a multivariable sensitivity analysis, based on a Monte Carlo simulation, is presented in section 6.6.5. To do this, the Crystal Ball™ software[3] has been used.

In addition to this base case, two other scenarios are going to be analyzed. In section 6.7, the possibility of spectrum trading between different mobile network operators (MNO) is explored as well as the price range that can be paid. Section 6.8 presents the business case results in case that the relay technology is used (the case base is based in a non-relay ROCKET architecture), and a comparison between relay-based and non relay-based ROCKET architectures and between relay-based ROCKET and FIREWORKS architectures.

6.1 Coverage assumptions

ROCKET deployment will consider covering 100% of urban and suburban areas and 20% in the case of rural areas as showed in Table 5. Market area and coverage area data come from FIREWORKS project except in the case of rural areas where a 20% of covered area has been considered (as it will be seen in section 6.7.4.3, the business model is not profitable for this geographic area, so, a limited coverage has been considered).

[3] More information available at http://www.oracle.com/crystalball/index.html

Coverage-based Calculation	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year10
Market Area – Urban (Km²)	1.952	1.952	1.952	1.952	1.952	1.952	1.952	1.952	1.952	1.952
Market Area – Suburban (Km²)	16.433	16.433	16.433	16.433	16.433	16.433	16.433	16.433	16.433	16.433
Market Area – rural (Km²)	282.412	282.412	282.412	282.412	282.412	282.412	282.412	282.412	282.412	282.412
% Covered – Urban	50%	95%	100%	100%	100%	100%	100%	100%	100%	100%
% Covered – Suburban	50%	60%	85%	100%	100%	100%	100%	100%	100%	100%
% Covered – Rural	1%	2%	4%	9%	20%	20%	20%	20%	20%	20%
Coverage Area – Urban (Km²)	976	1.854	1.952	1.952	1.952	1.952	1.952	1.952	1.952	1.952
Coverage Area – Suburban (Km²)	8.217	9.860	13.968	16.433	16.433	16.433	16.433	16.433	16.433	16.433
Coverage Area – Rural (Km²)	2.824	5.972	12.630	26.709	56.482	56.482	56.482	56.482	56.482	56.482

Table 5 Coverage assumptions

As a consequence, 57% of target country population is going to be covered by the ROCKET access network and constitutes the operator's overall potential market.

6.2 Market assumptions

As it was presented in section 2.2, the target markets considered in this business model are the following ones:

- Mobile communication market
- Mobile broadband market

In the mobile communication market, the operator using the ROCKET technology provides mobile voice services and broadband Internet access to their customers. The user terminal is assumed a smartphone. The service penetration considered in this business case is the one reached by mobile telephony services (higher than 100% in Western Europe) nowadays. Above these all potential customers and taking into account that the mobile operator using ROCKET architecture only covers 57% of these potential customers, an increasing market share that reaches 20% of the whole market is considered (see Figure 8).

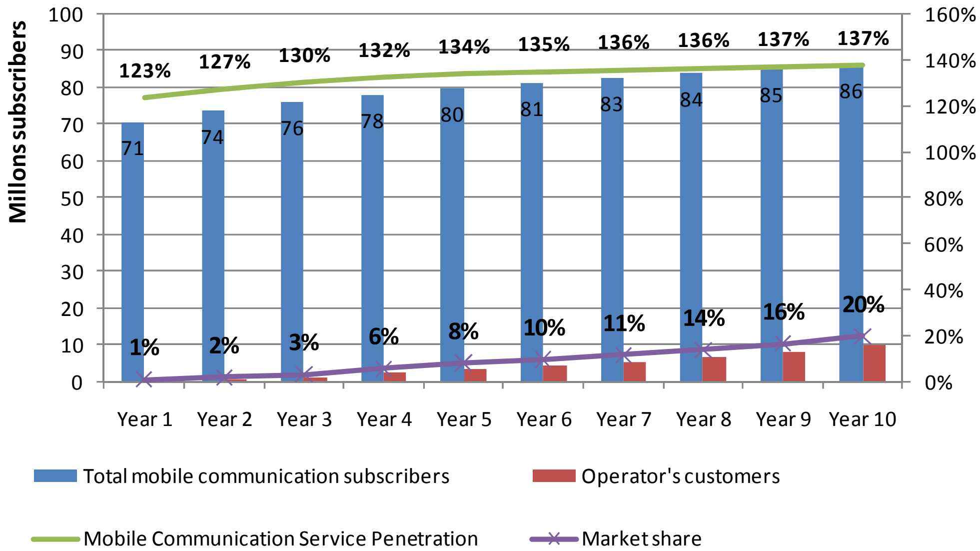

Figure 8. Subscribers of the mobile communication market and market share considered in the business case

In the case of mobile broadband market, the user terminal is a USB data modem. The service penetration of this emerging market is based on data presented by European Commission (2.9% in January 2009 and 4.7% in July 2009 in the case of Italy) and the prospective data of Analysys Mason (20% whole population in 2015 in Western Europe). Above these all potential customers, an increasing market share that reaches 20% of the whole market is considered (see Figure 9).

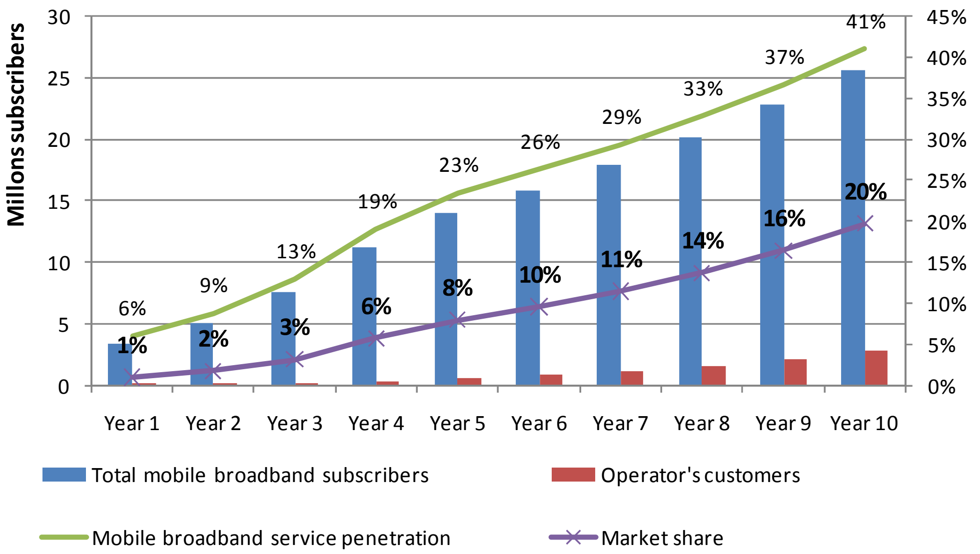

Figure 9. Subscribers of the mobile broadband market and market share considered in the business case

Despite the strong competition that characterized the mobile communication market, the differentiated characteristics of the services that could be provided with the ROCKET architecture (in terms of higher user bit rates, lower latency, etc. or the same services than HSPA architectures but with lower cost per MB) justify the high market shares considered.

Nevertheless, a sensitivity analysis of the profitability parameters with the variation of these market shares is presented in section 6.6.5.

Finally, Table 6 shows additional assumptions regarding the services provided to the customers.

Type of service	Parameter	Mobile Communication Customer	Mobile Broadband Customer
Mobile broadband service	Minimum downlink data rate (guaranteed in 70% of cell area)	1 Mbps	1 Mbps
	Minimum uplink data rate (guaranteed in 70% of cell area)	330 kbps	330 kbps
	Download data cap	300 MBytes	3 GBytes
	Yearly growth rate of download data cap	5%	5%
	Uplink to downlink busy-hour (BH) data traffic ratio	20%	20%
	Proportion of daily traffic in the busy hour	10%	10%
Voice services (Voice over IP)	Average voice traffic per subscriber (busy hour)	200 mE	--
	Yearly growth rate of voice service demand	5%	--
	Voice call data rate (ITU-T/G.729A)	24 kbps	--
	Blocking probability for telephony traffic	0,5%	--

Table 6. Parameter used to service dimensioning

6.3 Revenue assumptions

The revenue assumptions are based in the current pricing that can be found in the mobile communication and mobile broadband market of almost whatever European country nowadays. Moreover they are inspired in the services offered by Clearwire[4] in the United States, one of the operators that provide these services with WiMAX technology (802.16e) in the 2.6GHz frequency band.

Market	Parameter	Value
Mobile Communication	1st year ARPU	33 €/month
	Annual price trend per mobile communication subscriber	-2 %
Mobile broadband	1st year ARPU	50 €/month
	Annual price trend per mobile communication subscriber	-2 %

Table 9. Revenue assumptions

[4] See http://www.clearwire.com/shop/

6.4 Network architecture

The following figure shows the ROCKET architecture used for the business case. As it can be seen this architecture is based on the one used in FIREWORK project and is All-IP oriented.

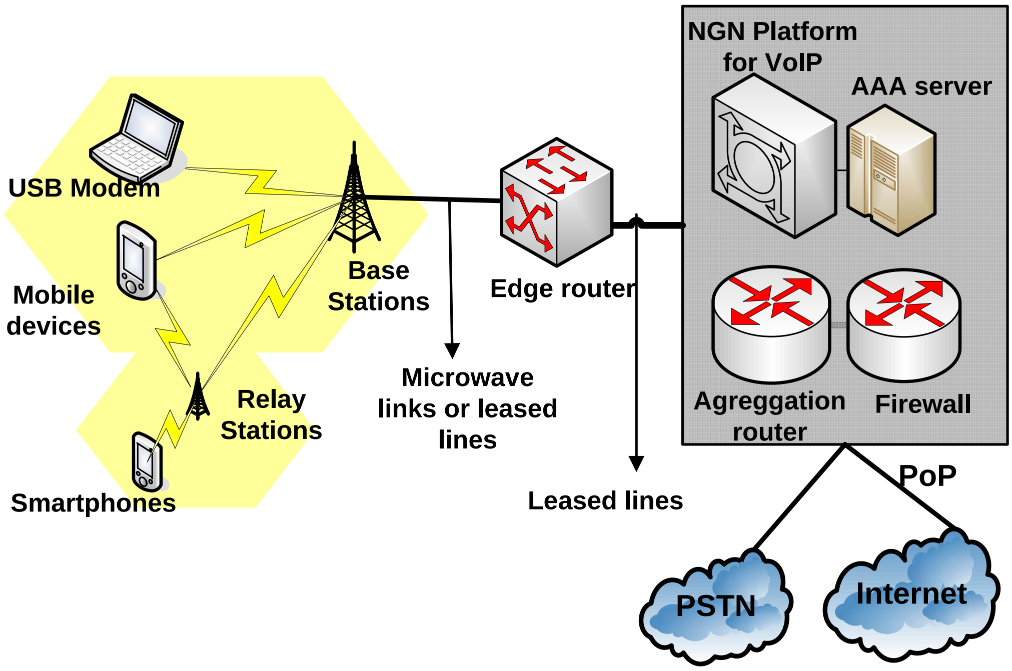

Figure 10. General architecture used in the business case

There are several parameters to be considered in the deployment of ROCKET technology, parameters that affect the final results of coverage and throughput. Considerations assumed will affect resources used as equipment or bandwidth, and therefore will affect deployment costs.

The main parameters considered in the base case are:

- Channel bandwidth of 15MHz, considering factor of reuse of 3, therefore 45 MHz of spectrum is required
- 2.6 GHz frequency band
- 3 sectors per cell (sectorization of 120º)
- Number of antennas: 2 at the BS and 2 at the MS (2×2)
- PUSC/FUSC channelization with coding across carriers, therefore no MIMO linear precoding is assumed in transmission[5]

Different channel bandwidth per sector (5, 10, 15 and 20MHz) and different antenna configurations (1×1 and 2×1) are also considered in the sensitivity analysis. The main results of coverage simulations used in the case base are shown in Table 7, Table 8, Table 9 and Table 10.

[5] The adoption of AMC transmission scheme for the fraction of static users could bring substantial benefits in terms of coverage both for the base case and for the relay-assisted transmission case.

				5 MHz bandwidth		
				Year 1	Year 3	Year 7
Urban	Input		Total DL Throuhput kbps/km2	**0,72**	**3,76**	**15,48**
			Total UL Throuhput kbps/km2	**0,56**	**2,46**	**8,09**
	No relaying	1x1	70% DL outage tx rate (Mbps)	1,175	0,982	1,421
			70% UL outage tx rate (Mbps)	0,390	0,327	0,474
			Cell radius (Km)	0,644	0,285	0,184
		2x1	70% DL outage tx rate (Mbps)	1,388	1,700	1,650
			70% UL outage tx rate (Mbps)	0,463	0,569	0,550
			Cell radius (Km)	0,767	0,385	0,229
		2x2	70% DL outage tx rate (Mbps)	1,490	2,346	1,710
			70% UL outage tx rate (Mbps)	0,497	0,782	0,570
			Cell radius (Km)	0,911	0,460	0,267
Suburban	Input		Total DL Throuhput kbps/km2	**0,18**	**0,77**	**2,81**
			Total UL Throuhput kbps/km2	**0,15**	**0,56**	**1,58**
	No relaying	1x1	70% DL outage tx rate (Mbps)	0,942	1,279	1,196
			70% UL outage tx rate (Mbps)	0,314	0,426	0,398
			Cell radius (Km)	1,081	0,687	0,404
		2x1	70% DL outage tx rate (Mbps)	1,131	1,572	1,585
			70% UL outage tx rate (Mbps)	0,377	0,524	0,526
			Cell radius (Km)	1,222	0,775	0,483
		2x2	70% DL outage tx rate (Mbps)	1,131	1,982	2,417
			70% UL outage tx rate (Mbps)	0,377	0,661	0,806
			Cell radius (Km)	1,445	0,898	0,575
Rural	Input		Total DL Throuhput kbps/km2	**0,1**	**0,25**	**0,63**
			Total UL Throuhput kbps/km2	**0,09**	**0,2**	**0,41**
	No relaying	1x1	70% DL outage tx rate (Mbps)	0,996	1,084	1,463
			70% UL outage tx rate (Mbps)	0,365	0,361	0,488
			Cell radius (Km)	1,634	1,515	1,100
		2x1	70% DL outage tx rate (Mbps)	0,901	0,980	0,877
			70% UL outage tx rate (Mbps)	0,334	0,327	0,292
			Cell radius (Km)	1,283	1,283	1,166
		2x2	70% DL outage tx rate (Mbps)	0,980	0,980	1,761
			70% UL outage tx rate (Mbps)	0,327	0,327	0,587
			Cell radius (Km)	1,716	1,716	1,454

Table 7. Coverage simulations in the non relay-based ROCKET architectures: 5MHz bandwith per sector

				10 MHz bandwidth		
				Year 1	Year 3	Year 7
Urban	Input		Total DL Throuhput kbps/km2	**0,72**	**3,76**	**15,48**
			Total UL Throuhput kbps/km2	**0,56**	**2,46**	**8,09**
	No relaying	1x1	70% DL outage tx rate (Mbps)	1,171	2,265	2,237
			70% UL outage tx rate (Mbps)	0,389	0,751	0,745
			Cell radius (Km)	0,844	0,399	0,229
		2x1	70% DL outage tx rate (Mbps)	1,540	3,012	2,913
			70% UL outage tx rate (Mbps)	0,513	1,001	0,971
			Cell radius (Km)	0,976	0,523	0,304
		2x2	70% DL outage tx rate (Mbps)	1,689	3,299	4,128
			70% UL outage tx rate (Mbps)	0,563	1,100	1,376
			Cell radius (Km)	1,033	0,597	0,364
Suburban	Input		Total DL Throuhput kbps/km2	**0,18**	**0,77**	**2,81**
			Total UL Throuhput kbps/km2	**0,15**	**0,56**	**1,58**
	No relaying	1x1	70% DL outage tx rate (Mbps)	0,938	1,404	2,559
			70% UL outage tx rate (Mbps)	0,313	0,467	0,853
			Cell radius (Km)	1,151	0,832	0,555
		2x1	70% DL outage tx rate (Mbps)	0,938	2,063	2,811
			70% UL outage tx rate (Mbps)	0,313	0,685	0,937
			Cell radius (Km)	1,427	0,992	0,633
		2x2	70% DL outage tx rate (Mbps)	0,827	1,842	3,199
			70% UL outage tx rate (Mbps)	0,276	0,614	1,066
			Cell radius (Km)	1,429	1,091	0,759
Rural	Input		Total DL Throuhput kbps/km2	**0,1**	**0,25**	**0,63**
			Total UL Throuhput kbps/km2	**0,09**	**0,2**	**0,41**
	No relaying	1x1	70% DL outage tx rate (Mbps)	0,980	0,980	2,239
			70% UL outage tx rate (Mbps)	0,327	0,327	0,746
			Cell radius (Km)	1,799	1,799	1,500
		2x1	70% DL outage tx rate (Mbps)	0,980	0,980	0,229
			70% UL outage tx rate (Mbps)	0,327	0,327	0,076
			Cell radius (Km)	2,175	2,118	1,568
		2x2	70% DL outage tx rate (Mbps)	0,980	0,980	0,980
			70% UL outage tx rate (Mbps)	0,327	0,327	0,327
			Cell radius (Km)	1,601	1,601	1,601

Table 8. Coverage simulations in the non relay-based ROCKET architectures: 10MHz bandwith per sector

				15 MHz bandwidth		
				Year 1	Year 3	Year 7
Urban	Input		Total DL Throuhput kbps/km2	**0,72**	**3,76**	**15,48**
			Total UL Throuhput kbps/km2	**0,56**	**2,46**	**8,09**
	No relaying	1x1	70% DL outage tx rate (Mbps)	0,777	3,180	2,934
			70% UL outage tx rate (Mbps)	0,259	1,060	0,978
			Cell radius (Km)	0,915	0,494	0,273
		2x1	70% DL outage tx rate (Mbps)	0,654	3,463	4,658
			70% UL outage tx rate (Mbps)	0,218	1,154	1,543
			Cell radius (Km)	1,055	0,624	0,349
		2x2	70% DL outage tx rate (Mbps)	0,453	4,473	5,654
			70% UL outage tx rate (Mbps)	0,151	1,491	1,885
			Cell radius (Km)	1,050	0,718	0,435
Suburban	Input		Total DL Throuhput kbps/km2	**0,18**	**0,77**	**2,81**
			Total UL Throuhput kbps/km2	**0,15**	**0,56**	**1,58**
	No relaying	1x1	70% DL outage tx rate (Mbps)	0,938	1,700	3,292
			70% UL outage tx rate (Mbps)	0,313	0,566	1,097
			Cell radius (Km)	1,192	0,923	0,643
		2x1	70% DL outage tx rate (Mbps)	0,938	1,904	3,859
			70% UL outage tx rate (Mbps)	0,313	0,635	1,286
			Cell radius (Km)	1,337	1,103	0,733
		2x2	70% DL outage tx rate (Mbps)	0,938	1,904	3,876
			70% UL outage tx rate (Mbps)	0,313	0,635	1,292
			Cell radius (Km)	1,266	1,207	0,896
Rural	Input		Total DL Throuhput kbps/km2	**0,1**	**0,25**	**0,63**
			Total UL Throuhput kbps/km2	**0,09**	**0,2**	**0,41**
	No relaying	1x1	70% DL outage tx rate (Mbps)	0,980	0,980	1,097
			70% UL outage tx rate (Mbps)	0,327	0,327	0,327
			Cell radius (Km)	1,851	1,851	1,771
		2x1	70% DL outage tx rate (Mbps)	1,171	1,171	1,171
			70% UL outage tx rate (Mbps)	0,324	0,324	0,324
			Cell radius (Km)	1,790	1,790	1,790
		2x2	70% DL outage tx rate (Mbps)	1,171	1,171	1,171
			70% UL outage tx rate (Mbps)	0,324	0,324	0,324
			Cell radius (Km)	2,118	2,118	2,118

Table 9. Coverage simulations in the non relay-based ROCKET architectures: 15MHz bandwith per sector

				20 MHz bandwidth		
				Year 1	Year 3	Year 7
Urban	Input		Total DL Throuhput kbps/km2	**0,72**	**3,76**	**15,48**
			Total UL Throuhput kbps/km2	**0,56**	**2,46**	**8,09**
	No relaying	1x1	70% DL outage tx rate (Mbps)	0,672	3,029	3,530
			70% UL outage tx rate (Mbps)	0,224	1,009	1,175
			Cell radius (Km)	0,942	0,599	0,309
		2x1	70% DL outage tx rate (Mbps)	0,436	4,451	4,692
			70% UL outage tx rate (Mbps)	0,145	1,484	1,552
			Cell radius (Km)	1,059	0,672	0,428
		2x2	70% DL outage tx rate (Mbps)	0,000	4,196	6,361
			70% UL outage tx rate (Mbps)	0,000	1,399	2,120
			Cell radius (Km)	1,103	0,761	0,481
Suburban	Input		Total DL Throuhput kbps/km2	**0,18**	**0,77**	**2,81**
			Total UL Throuhput kbps/km2	**0,15**	**0,56**	**1,58**
	No relaying	1x1	70% DL outage tx rate (Mbps)	0,938	1,935	3,347
			70% UL outage tx rate (Mbps)	0,313	0,645	1,113
			Cell radius (Km)	1,237	0,963	0,701
		2x1	70% DL outage tx rate (Mbps)	0,938	1,570	4,100
			70% UL outage tx rate (Mbps)	0,313	0,523	1,367
			Cell radius (Km)	1,259	1,179	0,819
		2x2	70% DL outage tx rate (Mbps)	0,938	0,938	3,137
			70% UL outage tx rate (Mbps)	0,313	0,313	1,046
			Cell radius (Km)	1,273	1,271	0,930
Rural	Input		Total DL Throuhput kbps/km2	**0,1**	**0,25**	**0,63**
			Total UL Throuhput kbps/km2	**0,09**	**0,2**	**0,41**
	No relaying	1x1	70% DL outage tx rate (Mbps)	1,171	1,171	1,171
			70% UL outage tx rate (Mbps)	0,324	0,324	0,324
			Cell radius (Km)	1,886	1,886	1,886
		2x1	70% DL outage tx rate (Mbps)	1,171	1,171	1,171
			70% UL outage tx rate (Mbps)	0,324	0,324	0,324
			Cell radius (Km)	1,728	1,728	1,728
		2x2	70% DL outage tx rate (Mbps)	1,171	1,171	1,171
			70% UL outage tx rate (Mbps)	0,324	0,324	0,324
			Cell radius (Km)	2,121	2,121	2,121

Table 10. Coverage simulations in the non relay-based ROCKET architectures: 20MHz bandwith per sector

6.5 Economic assumptions

6.5.1 General considerations on cellular costs

It is difficult to obtain an exact prediction of the costs of a cellular deployment because there are some aspects to be considered that could change final results, such as:

- Costs of available products may become quickly outdated, as the technology evolves, for example the cost of BS tends to decrease every year as it becomes possible to integrate smaller-size and less expensive components.

- Site acquisition, building and leasing costs depend mainly on the country, on the population density (urban vs. rural), on the proportion of new sites that will have to be acquired, versus existing cell sites that can be upgraded.
- Backhaul technology is typically site-specific: for a given deployment some sites can be connected via leased xDSL lines, some others via fiber (e.g. GPON), and some others via microwave.

There is a very a large number of possible configurations of base stations, including different alternatives for sites, transmission, etc. It could be deployed with macro, micro or pico base stations that imply different costs.

Cellular Backhauling also could adopt several configurations, we have wire or wireless backhaul options. For wire backhaul T1/E1 technology could be used, but also fibre, that provides higher throughput. For wireless backhaul we can chose ROCKET technology, that is expected to provide throughput of minimum 100 Mbps, and it seems to be cheaper than the wired solution.

To deal with this complexity, OPEX and CAPEX costs considered in ROCKET business case are estimated taking into account costs of others wireless network, such as WiMAX, GSM and UMTS.

6.5.2 CAPEX assumptions

The detailed ROCKET network CApital EXPenditure (CAPEX) used for the business case are indicated in Table 11. As a general consideration it is worth to mention that the same values than in FIREWORKS project are assumed except in the following aspects:

- MBS Backhauling: we assume different possibilities as used in the mobile termination rate model developed by Analysys Mason for Arcep in 2008 [3].
- Aggregation routers and Firewall of the core network: from the point of view of network operator we consider a small change in these prices.

Item	Description	Configuration quoted	Unit investment (€)	Asset lifetime	Investment Price Trend
Spectrum license acquisition	Spectrum licence acquisition in 2.6 GHz band		0.0325×MHz ×Pop (€)	20	-
MBS (Multihop Base stations)	Cost related to MBS equipment including cabinets, cables, antennas and feeders including installing and commissioning	CAPEX for a three sector node	33.000 €	10	-5%
		Adaptive antenna to be used in MBS	15.000 €	10	-5 %
MBS civil works	Cost includes MBS site acquisition, preparation and cabling, power	CAPEX for sites co-ubicated in sites used by other technologies[6]	10.000 €	20	2.5 %
		CAPEX for Greenfield site Urban and Suburban	75.000 €	20	2.5 %
		CAPEX for Greenfield site Rural	50.000 €	20	2.5 %
MRS (Multihop Relay Stations)	Cost related to the MRS devices including antennas and cables, installing and commissioning.	CAPEX for MRS node	8.000 €	10	-5 %
MRS acquisition and construction	Cost includes MRS site acquisition and preparation	CAPEX for Greenfield	5.000 €	20	2.5 %
MSS (Multihop Subscriber stations)	Smart Phones[7]			2	
	USB Data Modem[8]			3	
MBS Backhauling based on microwave links	HW associated to each microwave link	Base Unit	8.833 €	8	-5 %
	Bit rate	2Mbps (E1)	4.649 €	8	-5%
		8 Mbps	12.535 €	8	-5 %
		16 Mbps	18.596 €	8	-5 %
		34 Mbps (E3)	27.893 €	8	-5 %
		155 Mbps (STM-1)	89.675 €	8	-5 %

[6] In the base case, 30% of overall sites being roll-out each year can be co-ubicated in sites used by other technologies (such as GSM, UMTS, HSPA, etc.) through voluntary sharing arrangements among the different mobile operators or compulsory regulatory measures taken by national regulatory authorities.

[7] In this business model, the cost associated with the terminal subvention policy is not considered as a asset investment but a subscriber acquisition and retention cost.

[8] Idem 3.

Item	Description	Configuration quoted	Unit investment (€)	Asset lifetime	Investment Price Trend
Core network equipments and management	Edge router	Edge router managing up to 8 BS	15.000 €	8	-4%
	Aggregation routers	Aggregation router managing up to 8 Edge Router	28.000 €	8	-4 %
	Firewall	Firewall for 500 BS	120.000€	8	-4 %
	AAA server	AAA server for 300.000 subscribers	120.000 €	8	-4 %

Table 11. ROCKET network CAPEX assumptions.

6.5.2.1 Spectrum license acquisition

The spectrum licence acquisition investment considered is based in the price paid in the auction taken place in Norway in 2008 as it can be seen in Table 12.

Country	Frequencies obtained	Price of the unpaired spectrum (per MHz per population)
Norway	70 MHz TDD	0.0325 €
Sweden	50 MHz TDD	0.04 €
Finland	50 MHz TDD	0.0055 €
Hong Kong[9]	-	0.07 €

Table 12. Price paid for the unpaired spectrum of the 2.GHz frequency band in different countries (Source: Own elaboration from Analysys Mason [6])

However, as showed in the last table and in Figure 11 from Analysys Mason the price paid for the unpaired spectrum in 2.6GHz frequency band is very different in the several countries that have already auctioned the spectrum. Among the reasons that justify those differences it can be mentioned the market situation in term of competition and agents, the availability of other frequency bands, the technical and regulatory restrictions in the use of this band and in others, etc.

[9] There was no demand for unpaired spectrum in the Hong Kong auction, due to its reserve price of EUR0.07/MHz/pop. This data point therefore represents an upper limit of actual market demand and price.

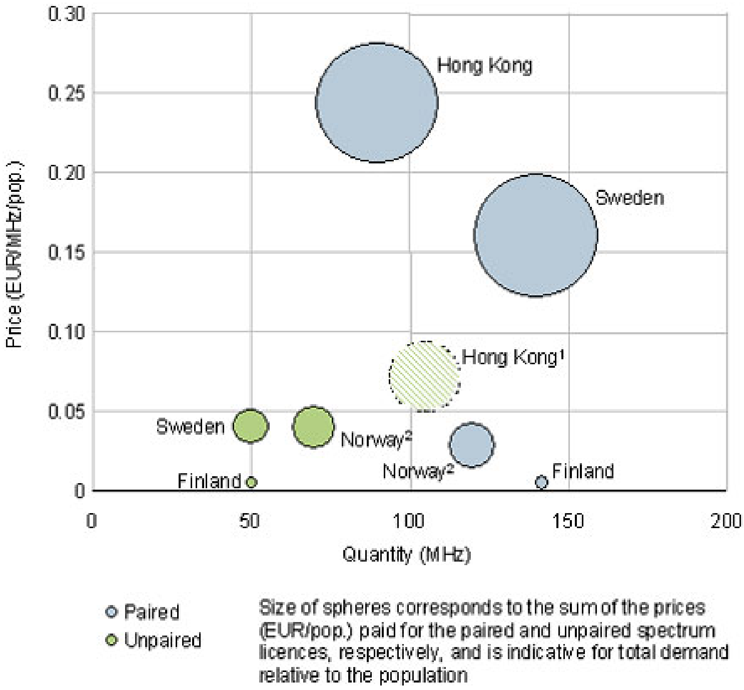

Figure 11 Value of paired and unpaired 2.6GHz spectrum in selected auctions [Source: Analysys Mason [6]]

6.5.3 OPEX definition

The OPerational EXpenditure (OPEX) includes: tower lease, Sales and Marketing Expense (including customer technical support), Network Operations, Equipment Maintenance, Base Station and Relay Station installation & Commissioning, Base Station and Relay Stations Site Lease Expense. Figures assumed are shown in Table 13 and Table 14.

As a general consideration it is worth to mention that the same values than in FIREWORKS project are assumed except in the following aspects:

- MBS Backhauling: we assume different possibilities based on microwave link or leased lines as used in the mobile termination rate model developed by Analysys Mason for Arcep in 2008 [3].
- Cost/Mbps at Internet Point Of Presence: a lower cost per Mbps has been considered.

Item	Description	OPEX (€/year)	Expenses Price Trend
Spectrum Licence Fee	As an auction has been considered, a spectrum licence fee is not applicable	0 €	2%
Multi-hop Base Stations (MBS) expense	MBS Tower Maintenance and Utilities	8.250 € (25% of CAPEX)	-
	Multihop Base stations Site Lease expense	14.400 €	2%
Multihop Relay Stations (MRS) expense	MRS Tower Maintenance and Utilities	1.200 € (15% of CAPEX)	-
	RS site lease expense	4.800 €	2%
MBS Backhauling based on microwave links	Base Unit	8% of CAPEX	-
	Whatever bit rate	8% of CAPEX	-
MBS Backhauling based on leased lines	2 Mbps (E1)	5.122 €	-10%
	8 Mbps	6.978 €	-10%
	16 Mbps	8.586 €	-10%
	32 Mbps (E3)	14.400 €	-10%
	155 Mbps (STM-1)	28.800 €	-10%
Core network equipments and management	Edge router	6% of CAPEX	
	Aggregation Point Tower Lease Expense (per Edge Router)	30.000 €	2%
	Aggregation router	6% of CAPEX	
	Firewall	6% of CAPEX	
	NGN Platform for VoIP	6 €/customer	-4%
	AAA server	6% of CAPEX	
	Site Rental and Utilities per POP	48.000 €	2%
	Cost/Mbps at Internet Point Of Presence	25 € / Mbps	-10%

Table 13. Network-related OPEX assumptions

Item	Description	OPEX	Expenses Price Trend
Marketing Programs	Marketing as % of sales	5% of sales	-
Subscriber Acquisition and Retention Costs	Promotion Cost per new or retention mobile broadband subscriber (related with the terminal subsidy policy)	50 €	-10%
	Promotion Cost per new or retention mobile communication subscriber (related with the terminal subsidy policy)	200 €	-10%
	% of new mobile communication subscribers from indirect sales	20%	
	Commission per Indirect Sales Channel Mobile Communication subscriber	50 €	
Other operating costs	Customer Service as cost for average subscriber	12 €/subscriber/year	
	Billing Expense as cost for subscriber	6 €/subscriber/year	
	Administration Overhead as % of OpEx	15% firsts years, and 10% after	
	Bad Debt Expense as % of Service Revenue	1,5%	

Table 14. Other non-network related OPEX assuptions

6.5.4 Financial assumptions

The main financial assumptions used in the business case are shown in the following table:

Financial Parameters	Value
Beginning Cash Balance	0€
Beginning NOL Balance	0€
WACC	15%
Statutory Corporate Tax Rate	35%
Perpetuity Growth Rate Factor	2%
Average Collection Period	30 days
Average Payment Period (providers, human resources, etc.)	30 days
Average Payment Period (CAPEX)	90 days

Table 15. Financial assumptions

6.6 ROCKET business case results: Base Case

As it was mentioned earlier, the economic feasibility of a new operator entrant in the European mobile communication market is presented in this section. In addition to the operator's business model viability, the cost distribution of a ROCKET-based access network in term of CAPEX and OPEX is presented and the main contributors to these costs are identified. To finish this section, a sensitivity analysis is presented.

6.6.1 Coverage

Table 16 shows the main coverage results of the business case. In the base case, relay base stations are not used. Terminals considered are 2×2 and the spectrum is 15MHz/sector.

In the business case, 30% of overall sites being roll-out each year can be co-located in sites used by other technologies (such as GSM, UMTS, HSPA, etc.) through voluntary sharing arrangements among the different mobile operators or compulsory regulatory measures taken by national regulatory authorities to facility new mobile network operator entrance. As it will seen in the sensitivity analysis, an increase in the percentage of sites co-ubicated has a relevant impact in the viability of the business case and it can be a positive regulatory measure if a national regulatory authority wants to encourage the entrance of new operators in mobile communication market.

Total capacity cell requirements		Y1	Y2	Y3	Y4	Y5	Y6	Y7	Y8	Y9	Y10
Total Busy Hour Traffic (DL)	$Mbps/km^2$	1,06	1,83	3,30	6,34	9,65	12,51	16,29	21,29	27,95	36,79
Total Base Stations		2.167	3.377	5.816	9.411	13.699	15.139	17.009	19.337	22.283	26.673
Total Relay Base Stations		0	0	0	0	0	0	0	0	0	0

Urban capacity cell requirements		Y1	Y2	Y3	Y4	Y5	Y6	Y7	Y8	Y9	Y10
Total Busy Hour Traffic (DL)	$Mbps/km^2$	0,77	1,38	2,59	5,11	7,85	10,24	13,39	17,57	23,14	30,57
BS cell radius		1,03	0,94	0,80	0,63	0,53	0,48	0,43	0,39	0,33	0,29
Nº relays per base station		0	0	0	0	0	0	0	0	0	0
Total Base Stations		351	809	1.160	1.916	2.633	3.261	4.056	5.052	6.693	8.690
Total Relay Base Stations		0	0	0	0	0	0	0	0	0	0

Suburban capacity cell requirements		Y1	Y2	Y3	Y4	Y5	Y6	Y7	Y8	Y9	Y10
Total Busy Hour Traffic (DL)	$Mbps/km^2$	0,22	0,35	0,57	1,03	1,52	1,94	2,49	3,22	4,17	5,43
BS cell radius		1,42	1,36	1,23	1,10	1,01	0,95	0,88	0,82	0,77	0,70
Nº relays per base station		0	0	0	0	0	0	0	0	0	0
Total Base Stations		1.574	2.056	3.573	5.205	6.225	7.037	8.112	9.443	10.749	12.831
Total Relay Base Stations		0	0	0	0	0	0	0	0	0	0

Rural capacity cell requirements		Y1	Y2	Y3	Y4	Y5	Y6	Y7	Y8	Y9	Y10
Total Busy Hour Traffic (DL)	$Mbps/km^2$	0,08	0,10	0,14	0,21	0,28	0,33	0,41	0,50	0,63	0,79
BS cell radius		2,12	2,12	2,12	2,12	2,12	2,12	2,12	2,12	2,12	2,05
Nº relays per base station		0	0	0	0	0	0	0	0	0	0
Total Base Stations		242	512	1.083	2.289	4.841	4.841	4.841	4.841	4.841	5.151
Total Relay Base Stations		0	0	0	0	0	0	0	0	0	0

Table 16. Coverage results in the base case

6.6.2 CAPEX

The table below shows the detail of the total CAPEX results of the business case. The main contributors are related to base stations, backhauling and cell site development.

	Y1	Y2	Y3	Y4	Y5	Y6	Y7	Y8	Y9	Y10
Spectrum	93,1 €	0,0 €	0,0 €	0,0 €	0,0 €	0,0 €	0,0 €	0,0 €	0,0 €	0,0 €
User terminal	0,9 €	1,6 €	3,5 €	7,2 €	9,1 €	6,8 €	9,9 €	15,1 €	19,0 €	19,1 €
Base stations	104,0 €	55,1 €	105,7 €	147,9 €	167,7 €	53,5 €	66,0 €	78,0 €	93,8 €	132,8 €
Sites	116,0 €	63,9 €	131,7 €	192,1 €	213,4 €	90,4 €	120,3 €	153,6 €	199,2 €	297,5 €
Backhaul	11,2 €	13,4 €	19,1 €	30,9 €	51,0 €	3,5 €	362,3 €	16,7 €	15,5 €	37,5 €
Backhaul equipment	8,6 €	4,8 €	10,3 €	15,8 €	23,0 €	3,3 €	4,1 €	4,9 €	11,4 €	12,7 €
Core network	1,7 €	0,8 €	1,9 €	2.6 €	3,1 €	1,1 €	1,5 €	1,6 €	3,2 €	3,4 €
Core transmission	0,0 €	0,0 €	0,0 €	0,0 €	0,0 €	0,0 €	0,0 €	0,0 €	0,0 €	0,0 €
Maintenance	16,8 €	7,0 €	13,6 €	19,8 €	23,4 €	7,9 €	28,2 €	13,5 €	17,1 €	25,2 €
Total	**352,3 €**	**146,8 €**	**285,7 €**	**416,3 €**	**490,7 €**	**166,5 €**	**592,2 €**	**283,5 €**	**359,3 €**	**528,2 €**

Table 17. Yearly CAPEX for the different asset considered (in million euros)

As it can be observed in Figure 12 the required annual investment increases from year 1 to 5 as a consequence of the increase of the area covered by the access network and in year 7 as a consequence of the renovation of equipment that reached their lifetimes. The increase of CAPEX in the rest of year is due to the additional capacity associated with the increase of customers attended and the volume of services consume by each customer.

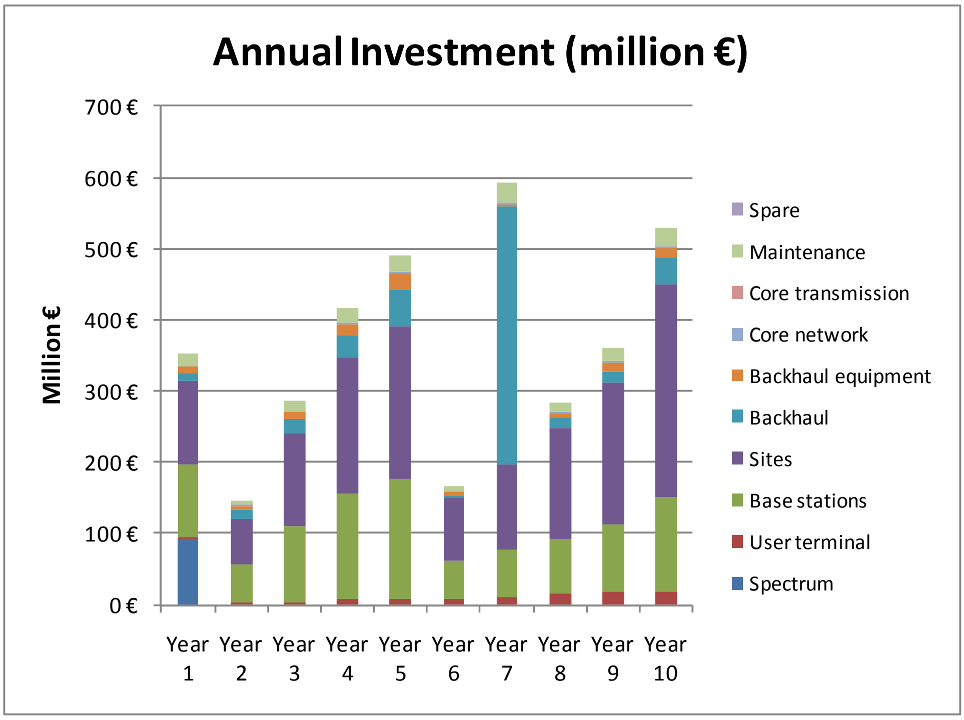

Figure 12. Yearly investment in the base case

Moreover, Figure 13 shows the accumulated investment along the ten years of the business case. It is evident as the main CAPEX contributors are related to the cell site installation and development, the base station equipment and the backhaul. The investment to acquire the spectrum license is relevant at the beginning but their importance falling up to 2% of total investment as it can be seen in Figure 14 which shows the accumulated CAPEX distribution after ten years.

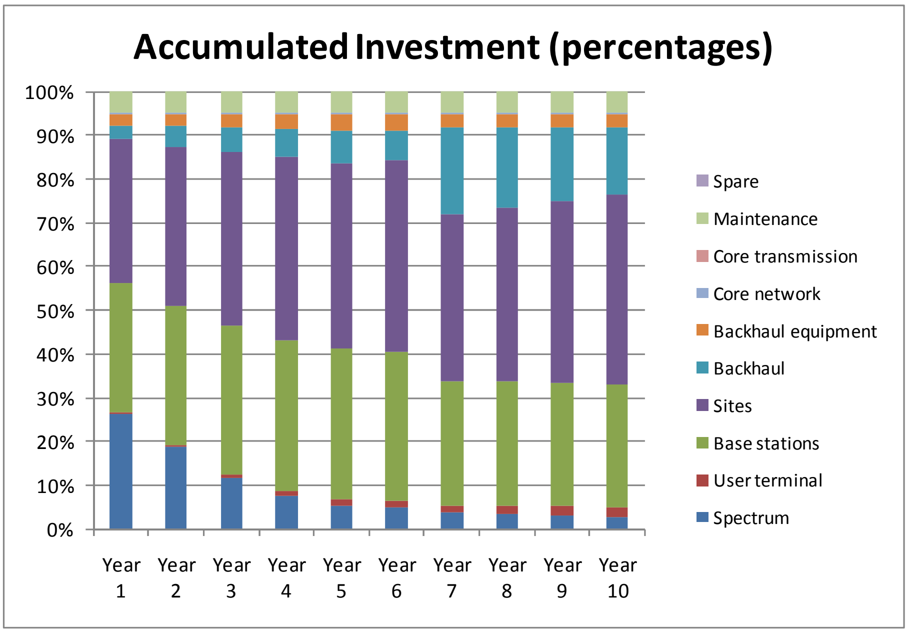

Figure 13. Distribution among the different asset of the accumulated investment in the base case

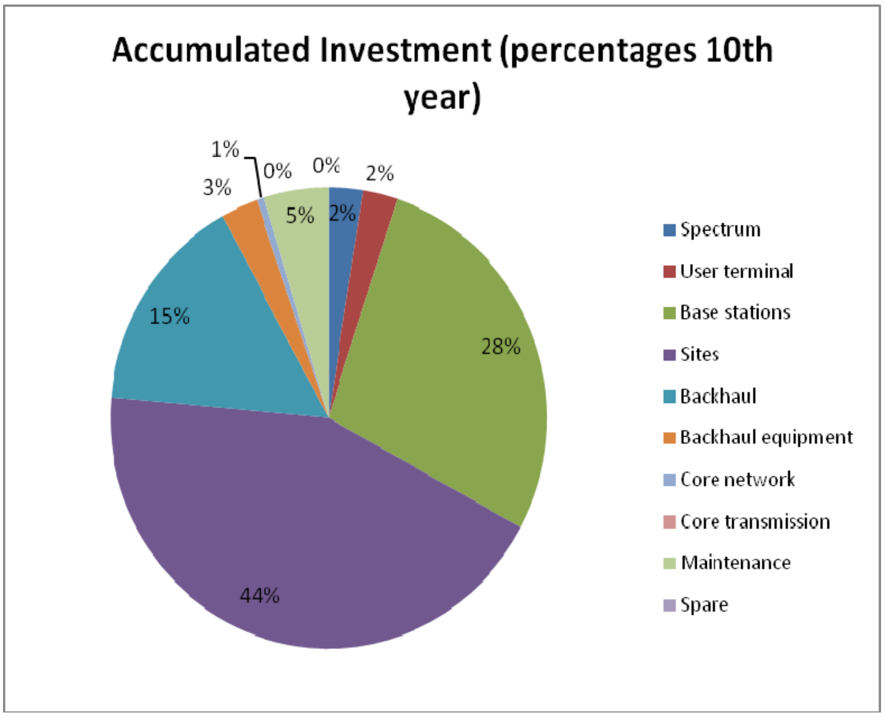

Figure 14. Accumulated CAPEX distribution after 10 years in the base case

6.6.3 OPEX

The following table and its associated figure show the detail of the network-related OPEX results of the business case. Figure 15 shows how network-related OPEX increases quite linearly presenting higher increases coinciding with the year of higher investment.

	Y1	Y2	Y3	Y4	Y5	Y6	Y7	Y8	Y9	Y10
Base stations	17,88 €	27,86 €	47,98 €	77,64 €	113,02 €	124,90 €	140,32 €	159,53 €	183,83 €	220,05 €
Sites	31,21 €	49,59 €	87,13 €	143,81 €	213,53 €	240,70 €	275,83 €	319,85 €	375,96 €	459,02 €
Backhaul	32,23 €	46,42 €	121,23 €	194,00 €	246,84 €	252,12 €	408,14 €	418,79 €	382,95 €	419,81 €
Backhaul equipment	8,73 €	13,90 €	24,46 €	40,56 €	60,78 €	68,14 €	77,66 €	89,57 €	104,69 €	127,30 €
Core network	2,74 €	5,47 €	10,87 €	20,26 €	30,46 €	35,11 €	40,72 €	47,44 €	55,46 €	65,71 €
Core transmission	0,08 €	0,18 €	0,36 €	0,71 €	1,10 €	1,25 €	1,44 €	1,66 €	1,93 €	2,25 €

Table 18. Network-related OPEX (million €)

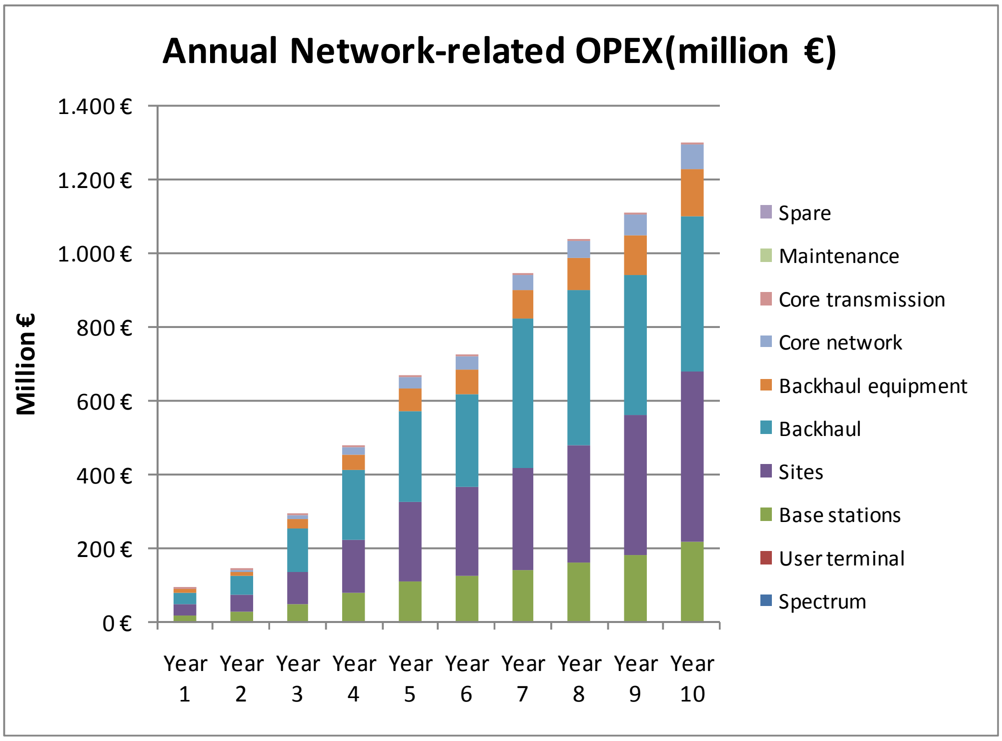

Figure 15. Annual network-related OPEX in the base case

As it results evident in Figure 16, the main contribution to these network-related OPEX is related to backhaul links and equipment maintenance, sites rental and base station maintenance.

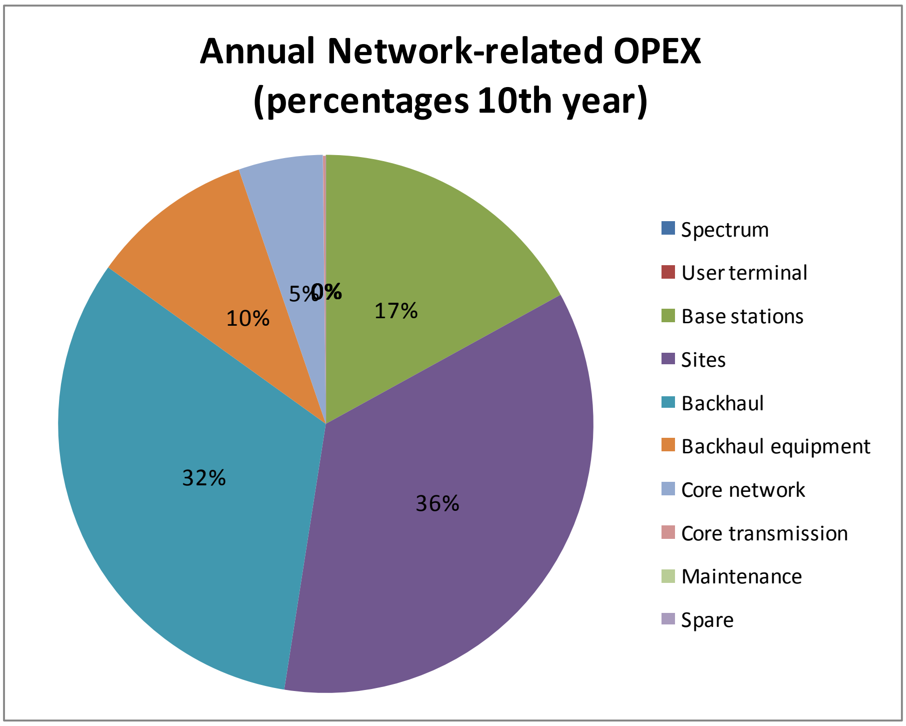

Figure 16. Annual network-related OPEX distribution after 10 years in the base case

In addition to network-related OPEX, additional costs such as those related with marketing, subscriber acquisition and retention and administrative expenses are also considered in the business case and presented in Table 19.

Marketing Programs (Fixed)	Y1	Y2	Y3	Y6	Y7	Y9	Y10
Other Marketing (% of sales)	5.0%	5.0%	5.0%	5.0%	5.0%	5.0%	5.0%
Sales	35.8 €	136.49 €	338.59 €	1,852.0 €	2,261 €	3,378.3 €	4,136.9 €
Total Fixed Marketing Expenses	**1.8 €**	**6.8 €**	**16.9 €**	**92.6 €**	**113.1 €**	**168.9 €**	**206.8 €**
Subscriber Acquisition Costs	**Y1**	**Y2**	**Y3**	**Y6**	**Y7**	**Y9**	**Y10**
Total Variable Mobile Broadband Marketing Expenses	€ 0.410	€ 1.107	€ 3.088	€ 8.9	€ 14.3	€ 18.5	€ 25.0
Total Variable Mobile Communication Marketing Expenses	€ 27	€ 44	€ 102	€ 220	€ 264	€ 311	€ 323
Total Commissions to Indirect Sales	€ 2	€ 3	€ 8	€ 23	€ 31	€ 45	€ 52
Total Subscriber Acquisition Costs	**29.05 €**	**48.03 €**	**113.34 €**	**251.92 €**	**309.00 €**	**374.69 €**	**399.81 €**
Other Operating Costs	**Y1**	**Y2**	**Y3**	**Y6**	**Y7**	**Y9**	**Y10**
Customer Service Expense	2.12 €	6.07 €	14.44 €	63.91 €	79.21 €	121.87 €	151.42 €
Billing Expense	1.06 €	3.04 €	7.22 €	31.95 €	39.60 €	60.93 €	75.71 €
Bad Debt Expense	0.54 €	2.05 €	5.08 €	27.78 €	33.92 €	50.68 €	62.05 €
Administrative Overhead	5.10 €	9.59 €	21.27 €	48.44 €	54.09 €	72.64 €	83.38 €
Total other operating costs	**8.82 €**	**20.75 €**	**48.01 €**	**172.09 €**	**206.82 €**	**306.11 €**	**372.56 €**

Table 19. Non-network-related OPEX[10] (in million euros)

[10] Years 4, 5 and 8 have been deleted to facilitate the visualization of the results.

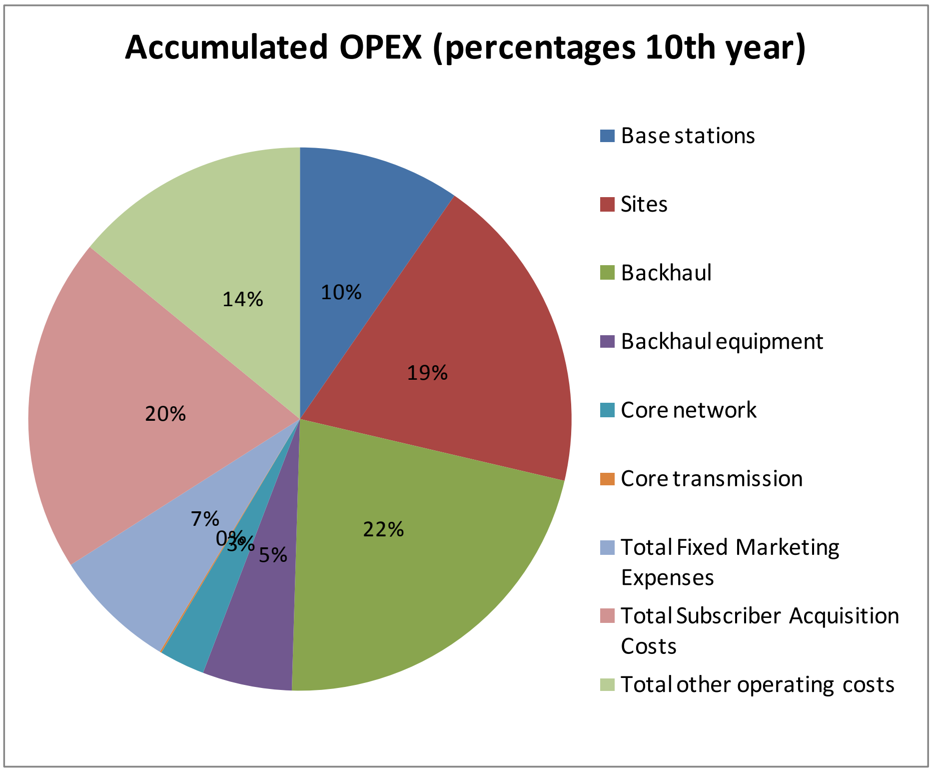

Figure 17 Accumulated total OPEX distribution after 10 years in the base case

Finally, Figure 17 shows the accumulated total OPEX after the tenth year of the business model. In addition to the already identified main contributors site rental and backhaul lease and maintenance, other important contributors are those related to subscriber acquisition and retention costs (mainly related with the user terminal subsidy policy) and other administrative and financial costs.

6.6.4 Financial results

Financial results indicate whether the new entrant based on ROCKET access network architecture may be economically profitable, and are mainly based on capital and operative expenditure and on the subscribers' revenues. These revenues are calculated taking into account the service penetration and market share considered in section 6.2 and in ARPUs presented in section 6.3.

	Y1	Y2	Y3	Y4	Y5	Y6	Y7	Y8	Y9	Y10
Revenues	35.81 €	36.50 €	338.60 €	757.91 €	1,354.50 €	1,852.09 €	2,261.55 €	2,762.78 €	3,378.39 €	4,136.90 €
Expenses	132.54 €	219.03 €	470.31 €	812.32 €	1,135.29 €	1,238.82 €	1,573.00 €	1,744.72 €	1,954.55 €	2,273.36 €
EBITDA	-96.72 €	-82.53 €	-131.71 €	-54.41 €	219.21 €	613.27 €	688.55 €	1,018.06 €	1,423.85 €	1,863.54 €
Gross margin over revenues	-270%	-60%	-39%	-7%	16%	33%	30%	37%	42%	45%
Depreciations and amortizations	78.29 €	111.51 €	176.13 €	269.89 €	381.11 €	413.36 €	559.49 €	612.77 €	654.22 €	764.06 €
EBIT	- 175.01 €	- 194.04 €	- 307.84 €	- 324.30 €	- 161.89 €	199.91 €	129.07 €	405.29 €	769.63 €	1,099.48 €
Net Profit	- 175.01 €	- 194.04 €	- 307.84 €	- 324.30 €	- 161.89 €	129.94 €	83.89 €	263.44 €	500.26 €	714.66 €
Net margin over revenues	-489%	-142%	-91%	-43%	-12%	7%	4%	10%	15%	17%

Table 20. Summary profit statement

The main financial results are indicated in Table 20 and in Figure 18 and Figure 19, where it can be seen that the operator starts to achieve a net profit in the 6th year, the same year that free cash flow turns positive.

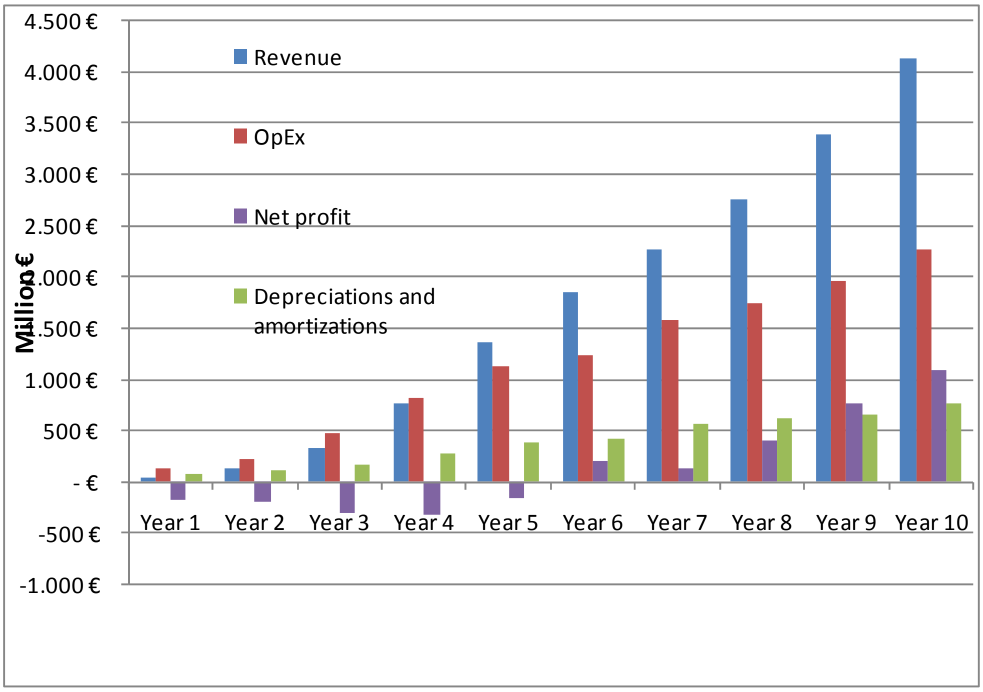

Figure 18. Profit statement in the base case

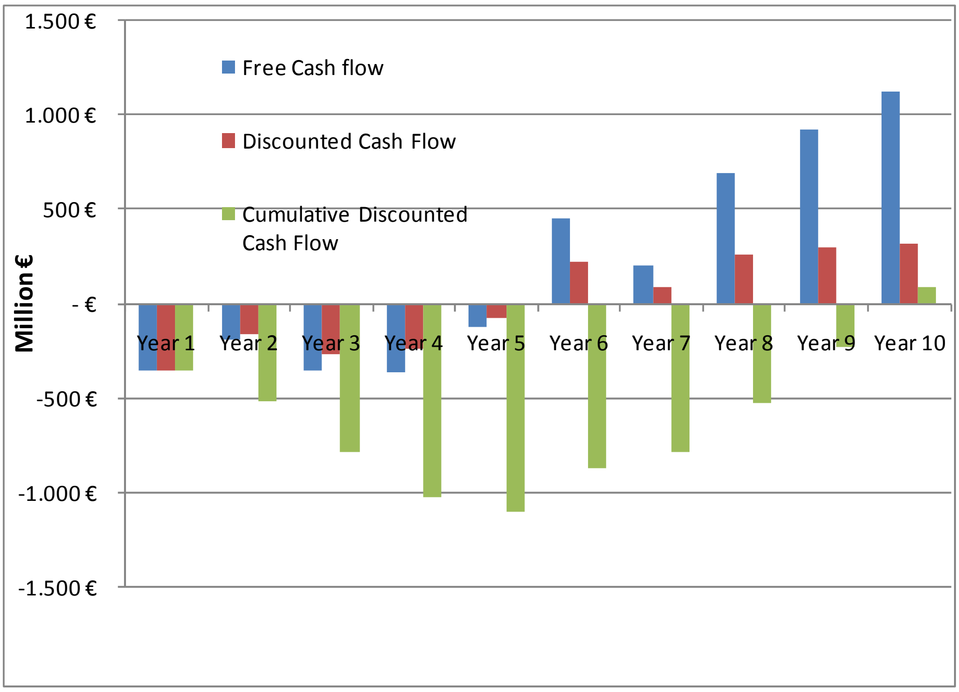

Figure 19. Free cash flow and accumulated discounted cash flow in the base case

Finally, the profitability parameters (Net present Value and Internal Rate of Return) of Table 21 show that the base case is hardly profitable with a NPV after 10 years of just 90.76 million euros.

NPV after 10 years	90.768 M€
IRR	16.591 %

Table 21. Profitability parameters (NPV after 10 years and IRR) in the base case

6.6.5 Sensitivity analysis

In this study, a multivariable sensitivity analysis based on a Monte Carlo simulation is utilized. To do this, the Crystal Ball™ software with Monte Carlo simulation and statistical analysis capabilities is used on top of the Excel-based ROCKET techno-economic model to perform automatically a large number of simulation runs and collect statistical data.

Compared to a stand-alone spreadsheet calculation model providing only a single result at a time based on e.g. the expected values of parameters, a model using Monte Carlo simulation can randomly generate thousands of values for each uncertain variable. The simulation engine pseudo-randomly selects a value from a defined range and shape of distribution for every variable and then recalculates the spreadsheet. By doing this repeatedly and by storing the results for later analysis, the engine simulates the model's behavior with numerous different combinations of parameter values.

The main benefit is that a sensitivity analysis done with Monte Carlo simulation can tell us what is probable, whereas traditional sensitivity analysis can only tell us what is possible [15]. Monte Carlo simulation then helps us to analyze the effects of simultaneous changes in different parameter values and to estimate the expected and extreme values of the business case.

However, even after a sensitivity analysis, the obtained numerical results must not be seen as universal outcomes for the real value of the business case. Instead, they represent the possible values of the business case in simulated market conditions with a number of underlying assumptions. Moreover, if the calculation model and parameter ranges do not reflect reality, the simulation outputs will not do it either.

Table 22 and its related Figure 20 show the assumptions made and the results obtained in the sensitivity analysis. A Gaussian distribution has been considered to model the different value of each input variable considered. The mean value for each variable is the one considered in the base case and is show in "Base case" column. In addition to a mean value, a more probable range of value has been considered resulting in the minimum and maximum values shown in the corresponding columns of Table 22. The minimum and maximum net present values obtained in the different simulations are presented in the table in millions €.

	Input			NPV after 10 years	
Variable	Min	Max	Base case	Min	Max
ARPU per mobile communication subscriber (€/month/customer)	30 €	36 €	33 €	- 278.2 M€	455.6 M€
Promotion Cost per new or retention mobile communication subscriber (€)	238 €	162 €	200 €	- 67.2 M€	248.7 M€
Final market share mobile broadband market (%)	15%	25%	20%	- 50.8 M€	212.7 M€
ARPU per mobile broadband subscriber (€/month/customer)	45 €	55 €	50 €	- 22.0 M€	203.5 M€
Final mobile broadband penetration (%)	34%	46%	40%	- 9.8 M€	164.1 M€
WACC (%)	17%	13%	15%	11.3 M€	181.8 M€
Number of sites that can be co-ubicated in sites used for other technologies (%)	17%	43%	30%	19.0 M€	162.4 M€
Download data cap per mobile broadband subscriber (MByte/month/subscriber)	3640	2359	3000	- 1.0 M€	138.8 M€
Final % of area coverage in rural areas	29%	11%	20%	12.4 M€	145.4 M€
Final market share mobile communication market (%)	18%	21%	20%	35.8 M€	113.7 M€
Download data cap per mobile communication subscriber (MByte/month/subscriber)	338.4	261.5	300	29.1 M€	94.4 M€
Promotion Cost per new or retention mobile broadband subscriber (€)	56 €	44 €	50 €	85.5 M€	95.9 M€
Price per MHz and pop for spectrum acquisition (€/MHz/pop)	0.0346	0.0304	0.0325	86.8 M€	94.6 M€

Table 22. Result of the sensitivity analysis of the base case: NPV after 10 years

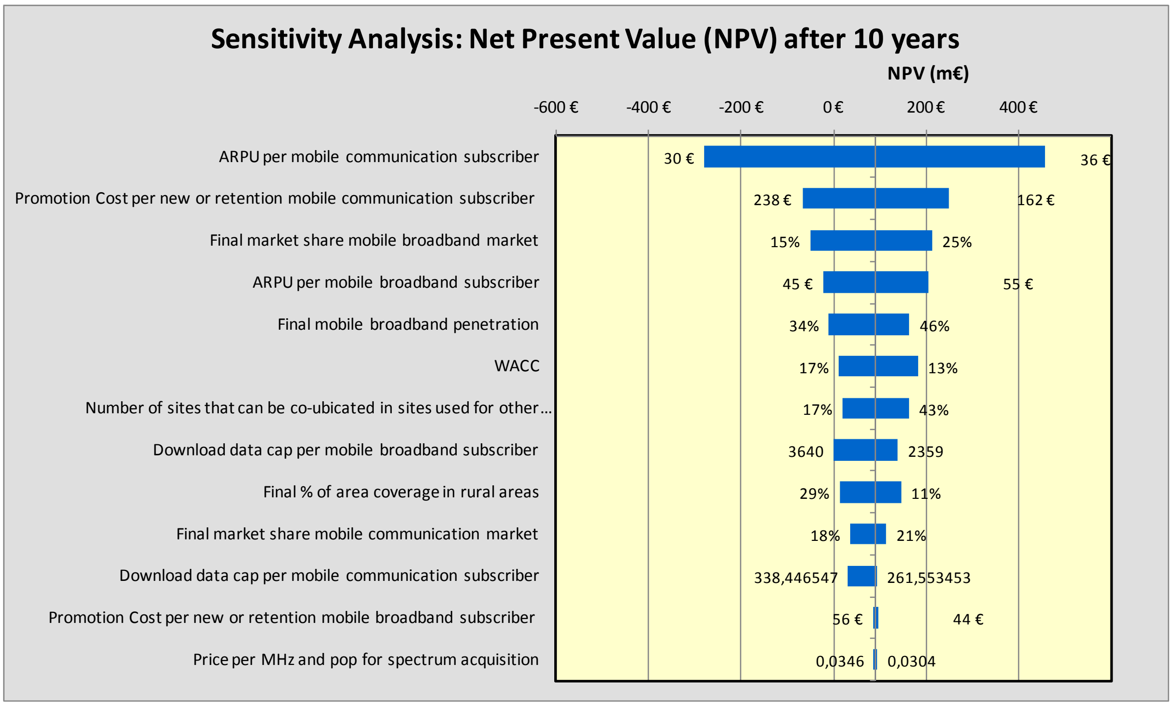

Figure 20. Result of the sensitivity analysis of the base case: NPV

According to the results obtained in the sensitivity analysis, some conclusions can be made:

- As it could be expected, input values relating to revenues (ARPUs and market shares) have the greatest impact in the profitability parameters. The role of ARPUs is more important than market share because it provides an increase or decrease of total revenues without affecting the expenses; the ARPU for mobile communication subscriber affects more than the one for mobile broadband subscribers due to the higher number of mobile communication subscribers (higher penetration of the service).

- The other important variable that has to be considered in making a business model for ROCKET-based access network is the cost of each mobile user terminal (smartphones). As it can be seen in last figure, the promotion and retention cost per subscriber is the second variable in terms of impact in NPV and is associated with the mobile operators' user terminal subsidy strategy. In this business model, a 200 € subsidy has been considered and represents an important cost per subscriber. The rest of the smartphone price has to be paid upfront by the customer and it is not considered in the business case.

- Another variable that plays a key role is the cost of capital. As a measure of the values that the WACC can have, based on operator financial data from Bloomberg, the European mobile industry's average WACC was 8% in 2006 [18]. NRAs have made similar estimates of mobile industry cost of capital. For example, OFCOM's Statement on Mobile Call Termination estimated UK mobile industry WACC to be 9–11.5% However, in our business case we have considered the risk associated with the entrance on a highly competitive market as it is the European communication market. Consequently, a WACC of 15% and a range of 13-17% in the sensitivity analysis have been considered in the base case to take into account this risk prime.

- The percentage of sites co-ubicated in sites used by other technologies (such as GSM, UMTS, HSPA, etc.) has also an importance because it let increase or decrease the cell site development and site lease costs, which are ones of the main contributors to CAPEX and OPEX (see sections 6.6.2 and 6.6.3).

This site co-ubication can be made through a voluntary sharing arrangement among the new entrant and different mobile operators or as a consequence of a compulsory regulatory measure taken by national regulatory authorities. The adoption of this measure could be an interesting way of reducing the entrant cost of new operators, encouraging the infrastructure-based competition, and it has been considered in several countries. As an example, the recently award of the 4th 3G license to Free Mobile in France can be mentioned: the French national regulatory authority, Arcep, gives [7] this new entrant the rights of access to the three other mobile operators' GSM sites when used for 3G, for the collocation of 3G equipment.

- Finally, the model shows a special sensibility to other variables such as the final percentage of coverage in rural areas (as a consequence of the non-profitability of this geotype as it will be shown later in this section) and the volume of monthly data that each mobile broadband subscriber can download (it increases the capital and operational cost as a consequence of the higher traffic).

In addition to the multivariable sensitivity analysis, two additional scenarios are going to be analyzed and presented.

The first scenario shown in Figure 21 presents the impact of the total bandwidth available for the operator in the profitability of the business (in terms of NPV after 10 years and IRR and considering the rest of variables as defined in the base case).

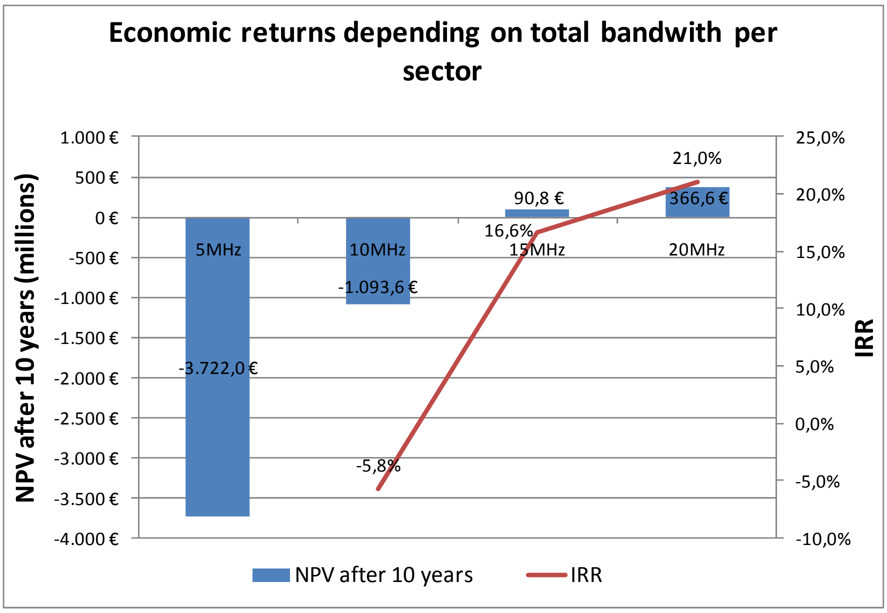

Figure 21. Economic returns depending on total bandwidth per sector in the base case

As it can be seen, only in the case of 15MHz or 20MHz per sector, which corresponds to a total of 45MHz or 60MHz in the 2.6GHz frequency band respectively, the base case is profitable. As a consequence, in the case of using the channelizing proposed by CE, all the 50MHz for TDD technology should be assigned to one operator in order to guarantee the profitability of its business case.

In the second scenario, the economic return depending on the geotypes where the ROCKET-based access network is rolled out is presented (Figure 22).

These results seem to confirm the idea that the provision of mobile broadband services in rural areas should be based in lower frequency bands, such as 900MHz after the refarming of this band is concluded and the 800MHz frequency band resulting from digital dividend.

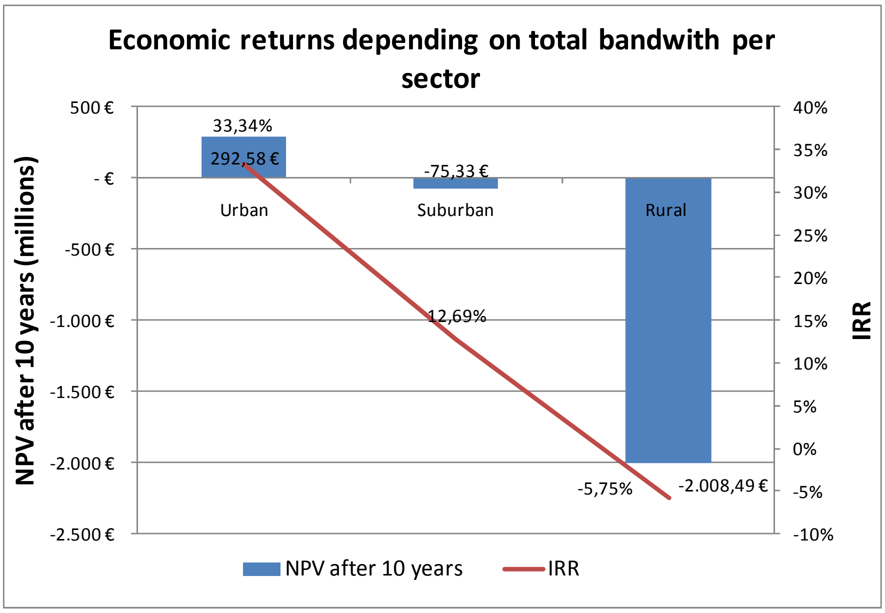

Figure 22. Economic returns depending on the geotypes where the ROCKET-based access network is rolled out

In addition to that, the business case shows a high profitability in urban areas. As a consequence, the ROCKET technology in the 2.6GHz can be used for different operators (such as cable or alternative operators that provide broadband services based on the access to incumbent networks) to provide mobile communication services as a consequence of their needs to respond to fixed-mobile convergence.

As an example of this trend, the consortium made up of bigger cable operators in the USA can be cited: Comcast, Time Warner Cable, Cox Communications and Bright House Networks, with Sprint Nextel, called SpectrumCo, to acquire 137 wireless spectrum licenses for AWS frequency band (Advanced Wireless Services: 1.7-2GHz frequency band) for a combined $2.37 billion and the investment of Comcast, Time Warner Cable and Bright House Networks in Clearwire that let them provide mobile broadband services with the 2.6GHz mobile WiMAX network being roll-out by Clearwire. In fact, Comcast has already announced [8] the provision of mobile broadband services in Portland City, USA.

6.7 ROCKET business case results: Aggregated Spectrum Usage

In this section, an introduction to the possibilities that dynamic spectrum access brings is presented, as well as the characteristics of a secondary spectrum market. After that, a simple model, that let us illustrate the possibilities that a secondary spectrum market offers to different operators, is presented considering different spectrum assignment and geographic areas, and a method to estimate the prices of these transactions is proposed.

6.7.1 Dynamic Spectrum Access (DSA)

The latter technology will enable radio equipment to re-tune and adapt their transmission parameters so that the radio transmissions could fit within identified white spaces or connect to available networks. Technologies studied in ROCKET project could open significant opportunities for truly open access to and potentially limitless use of natural radio spectrum resources. More intensive use of spectrum without the need to migrate incumbent users offers the possibility of large economic and social benefits for all Europeans. This self-managed spectrum access could be termed by Dynamic Spectrum Access (DSA).

Three different DSA methods could be considered:

DSA 1: *Low power secondary transmission simultaneously with the primary user.* In this method, the secondary user is allowed to transmit simultaneously with the primary user. However, since simultaneous transmissions can lead to interference, it is necessary in this method to put some constraints on the secondary user transmission. First and foremost, the transmission power of the secondary user should be maintained below a threshold such that there is no distortion of the primary user signal. Secondly, the modulation techniques which can be used by the secondary user also need to be pre-approved by the primary user, in a way that the secondary transmission doesn't cause interference with the primary user transmission. An advantage of this type of spectrum access is that the secondary transmission need not be time-limited, even if the primary user may still prefer it to be so.

DSA 2: *High power secondary transmission in unused spectrum.* In this method, the primary user gives a time-limited license to the secondary user to utilize spectrum which he/she is not currently utilizing. Usually these types of transactions are long-term. The primary user determines the amount of spectrum necessary during the day. This usage is calculated, such that it can enable primary user transmission even during the peak load conditions in the network. They then enter into a transaction to lease the remaining spectrum they possess to the secondary user, usually as a long-term arrangement.

DSA 3: *Intermittent secondary transmission by spectrum sensing when primary user is inactive.* This type of spectrum usage is most applicable when the primary user transmission occurs in bursts. In this method, the secondary user radio senses the spectrum before it transmits. If the spectrum is not being utilized by the primary user, then the secondary transmission takes place. If the secondary user detects a primary user in transmission, it will back-off and try later after some time.

In ROCKET we assume a variation of DSA2 method to define the business model for aggregated spectrum usage assumption.

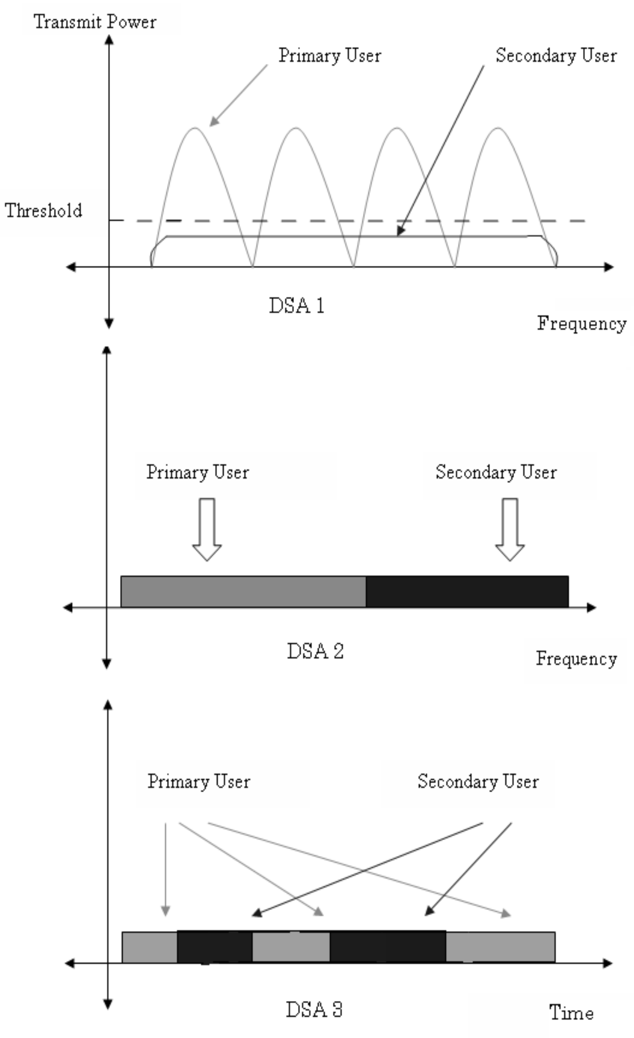

Figure 23. Different Dynamic Spectrum Access Techniques

6.7.2 Secondary Spectrum Market

When the allocated spectrum is not fully utilized, the spectrum owner (or primary user) has an opportunity to sell this radio spectrum to other users (i.e., secondary users) to generate revenue. This is referred to as the spectrum trading mechanism which involves spectrum selling and buying. For spectrum trading, one of the challenging issues is pricing; for example, how to set the spectrum price in a competitive environment where multiple sellers offer spectrum to the buyer, so that the sellers (e.g., primary services providers) are satisfied and their profits are maximized.

Here comes the concept of secondary market, which refers to spectrum trading, that allows holders of spectrum usage rights to transfer these rights to other agents, in particular the sale or rental of those rights, creating a new market.

In the case of establishing a secondary market for spectrum, it is always necessary to define primary allocation mechanisms for establishing an initial allocation of spectrum between different actors as a step towards the implementation of this secondary market.

The final goal is to achieve more efficient use of radio spectrum, increase the value of services provided to the users, increase transparency in its management, eliminate access barriers, facilitate the introduction of new services and promote innovation in new technologies.

6.7.3 Model definition

In this section, a simple model that let us illustrate the possibilities that a secondary spectrum market offers to the different operators is going to be presented.

The general assumption made for the simulation of this secondary spectrum market is that operators that have a set of radio spectrum frequencies are willing to achieve the maximum economic benefit. This economic profit can be achieved in two different ways. Firstly, by using all these radio spectrum resources in the roll-out of their mobile network, with which they provide the communication services, in order to decrease the cost of this roll-out, increasing therefore the economic benefit achieved in the provision of these services (as it was shown in Figure 21, the higher the bandwidth per sector used in the network roll-out, the lower the network costs and the higher the economic returns considering invariable the rest of assumptions). Secondly, they could make available a subset of their radio spectrum resources in the secondary spectrum market. That would have economic sense if there were another operator willing to pay for that subset of frequencies a price higher than the additional cost assumed by the seller/lessee operator as a consequence of the lower bandwidth per sector used in its network. Likewise the buyer/lessor operator would only pay that price if the cost savings in the roll-out of its own network with higher bandwidth per sector is higher than that price.

In order to simulate this secondary spectrum market, different kinds of mobile operators are going to be considered. All those operators are presented in the mobile communication market (providing mobile communication services and mobile broadband access as defined in the case base) but they differ from each other in having different market share. These different operators represent cases that are or will be present in the mobile communication market and, as a consequence of their diverse market shares, they will have a demand for higher or lower bandwidth making the transactions of radio spectrum resources among them very likely.

The operators considered in our study are three and are presented next:

- **New entrant:** A new entrant in the mobile communication market taking advantage of the possibilities that ROCKET technology brings. It is the same operator considered in the base case and its market share increases from 1% in the first year to 20% in the 10th year.
- **Medium operator:** A medium operator with a market share increasing slowly from 15% in the first year to 19% in the 10th year.
- **Incumbent:** An incumbent operator with a market share falling from 30% in the first year to 26% in the 10th year.

In addition to that, different spectrum assignments are going to be considered for each of the mobile operators. More specifically, the following spectrum assignments are supposed:

- A total of 15MHz, corresponding to a maximum of 5MHz per sector
- 30MHz, corresponding to a maximum of 10MHz per sector
- 45MHz, corresponding to a maximum of 15MHz per sector
- 60MHz, corresponding to a maximum of 20MHz per sector

From now on, all spectrum assignments are defined in terms of bandwidth per sector taking into account that a factor of reuse of 3 is considered.

As it can be observed, all these combination of operators and assignments cannot happen at the same time in the 2.6GHz frequency band. However, some of them could happen, so, it is interesting to explore all different combinations.

Finally, the study is going to be carried out separately for each of the geographic areas considered in the case base: urban, suburban and rural areas. The reason to do that is that each of these areas has their own specific characteristics in terms of the amount of radio spectrum resources needed for the roll-out of the networks, the requirements that make the business case profitable, etc. making advisable to do a study for each.

More specifically, the model considered for the simulation of the supply and demand of radio spectrum resources and their related prices is going to be presented.

Simulation of the radio spectrum supply:
An operator A with a total of X_A MHz/sector would be willing to make available in the secondary spectrum market an amount of Y MHz/sector for a price higher than the increase of network costs associated with the roll-out with a maximum of (X_A-Y) MHz/sector instead of with X_A MHz/sector.

Radio spectrum supply: Minimum Price = Network roll-out costs with (X_A-Y) MHz/sector - Network roll-out costs with X_A MHz/sector

Simulation of the radio spectrum demand:
An operator B with a total of X_B MHz/sector would be willing to acquire in the secondary spectrum market an amount of Y MHz/sector for a price lower than the network cost saving associated with the roll-out with a maximum of (X_B+Y) MHz/sector instead of with X_B MHz/sector.

Radio spectrum demand: Maximum Price = Network roll-out costs with X_B MHz/sector - Network roll-out costs with (X_B+Y) MHz/sector

The transaction of this Y MHz/sector between the operator A and B only would happen if the maximum price set by the spectrum demand is greater than the minimum price set by the spectrum supply. The final transaction price would be in the range defined by these minimum and maximum prices being farther or closer from the average price depending on how the negotiation process occurs between the buyer/lessor operator and the seller/lessee operator.

The estimation of these minimum and maximum prices in the different cases to simulate (for the 3 kinds of operators, 4 possible spectrum assignments and three geographical areas) is based on the calculation of the net present value after 10 years. Since the revenues of the different operators are considered constant independently of the total spectrum bandwidth used in the roll-out, the difference between the net present values in the different cases (network roll-out with different spectrum bandwidth) let determine the difference in network roll-out costs.

6.7.4 Results

This section presents the results obtained by applying the model of secondary spectrum market defined above. The results are obtained for the 3 types of operators, 4 possible spectrum assignments and three geographical areas.

The rest of assumptions corresponds to those defined in the base case (see sections from 6.1 to 6.5) with the exception of market shares (the values used for the three types of operators are the ones defined in the previous section) and the fact that the different geographical areas are analysed separately and considering a 100% coverage area since the first year of network roll-out.

6.7.4.1 Case 1: Urban areas

The Table 23 and Table 24 present the net present values (NPV) after ten years and the Internal Rate of Return (IRR) for the different mobile operators and spectrum assignments considered.

NPV after 10 years (M€)	5 MHz/sector	10 MHz/sector	15 MHz/sector	20 MHz/sector
New entrant	- 883,975 €	62,596 €	289,205 €	466,324 €
Medium operator	- 747,57 €	756,35 €	1.171,82 €	1.546,08 €
Incumbent	- 851,14 €	1.427,21 €	1.907,10 €	2.643,88 €

Table 23. NPV after 10 years for the different mobile operators and spectrum assignments considered in urban areas

IRR	5 MHz/sector	10 MHz/sector	15 MHz/sector	20 MHz/sector
New entrant	-	18,88%	32,17%	39,59%
Medium operator	-	36,87%	53,86%	68,90%
Incumbent	3,81%	43,23%	56,15%	83,89%

Table 24. IRR for the different mobile operators and spectrum assignments considered in urban areas

The different columns of the above tables represent the different possible spectrum assignments of the different operators: a maximum of 5MHz/sector, 10MHz/sector, 15MHz/sector and 20MHz/sector.

Then, the different possible spectrum transactions of a total of 5MHz/sector among the different operators and spectrum assignments are going to be explored.

As described in the preceding section, the price of the radio spectrum supply in the secondary market would be determined by the additional costs the seller/lessee operator would have to assume in its network roll-out as a consequence of using a lower spectrum bandwidth per sector, specifically 5MHz less per sector. Thus, the Table 25 shows the increase in costs to the various operators considered and would come to determine the minimum price for which these operators will be interested in selling or renting these 5MHz/sector.

Spectrum supply: 5MHz/sector (in M€)	From 10 MHz to 5 MHz/sector	From 15 MHz to 10 MHz/sector	From 20 MHz to 15 MHz/sector
New entrant	946,571 €	226,609 €	177,118 €
Medium operator	1.503,919 €	415,464 €	374,259 €
Incumbent	2.278,342 €	479,899 €	736,771 €

Table 25. Minimum prices for the transaction of 5 MHz/sector in urban areas representing the radio spectrum supply

Similarly, the demand of radio spectrum is derived from the cost savings the different operators experience as a consequence of the acquisition of additional spectrum resources in the secondary market that let them roll out their networks with a higher spectrum bandwidth per sector, specifically an additional 5MHz/sector. These cost savings would come to determine the maximum price that these operators would be willing to pay for those additional 5MHz/sector (see Table 26).

Spectrum demand: 5 MHz/sector (in M€)	From 5 MHz to 10 MHz/sector	From 10 MHz to 15 MHz/sector	From 15 MHz to 20 MHz/sector
New entrant	946,571 €	226,609 €	177,118 €
Medium operator	1.503,919 €	415,464 €	374,259 €
Incumbent	2.278,342 €	479,899 €	736,771 €

Table 26. Maximum prices for the transaction of 5 MHz/sector in urban areas representing the radio spectrum demand

The combination of the radio spectrum demand and supply, as defined in previous paragraphs, makes it possible to determine the couple of operators for which the transfer of 5MHz/sector would make economic sense. These potential transactions are shown in Table 27. Among all the possible combinations, the transaction would only make economic sense if the maximum price willing to pay for the buyer/lessor operator is greater than or equal to the minimum price fixed by the seller/lessee operator. The combinations for the radio spectrum transaction that are possible are shown in green on the table and the average price corresponding to those minimum and maximum prices is included. The combinations for the radio spectrum transaction that do not make sense are shown in red and do not include any numbers.

		Seller/Lessee								
Buyer/Lessor		New entrant			Medium operator			Incumbent operator		
		10-5 MHz/sect	15-10 MHz/sect	20-15 MHz/sect	10-5 MHz/sect	15-10 MHz/sect	20-15 MHz/sect	10-5 MHz/sect	15-10 MHz/sect	20-15 MHz/sect
New entrant	5-10 MHz/sect	947 €	587 €	562 €		681 €	660 €		713 €	842 €
	10-15 MHz/sect		227 €	202 €						
	15-20 MHz/sect			177 €						
Medium operator	5-10 MHz/sect	1.225 €	865 €	841 €	1.504 €	960 €	939 €		992 €	1.120 €
	10-15 MHz/sect		321 €	296 €		415 €	395 €			
	15-20 MHz/sect		300 €	276 €			374 €			
Incumbent operator	5-10 MHz/sect	1.612 €	1.252 €	1.228 €	1.891 €	1.347 €	1.326 €	2.278 €	1.379 €	1.508 €
	10-15 MHz/sect		353 €	329 €		448 €	427 €		480 €	
	15-20 MHz/sect		482 €	457 €		576 €	556 €		608 €	737 €

Table 27. Potential transactions of 5 MHz/sector among the mobile operators considered in urban areas and their average prices in m€

In view of the above table, the following conclusions can be drawn:

- As it could be expected, the largest beneficiary of radio spectrum in the secondary market is the incumbent operator for all assignments considered. The larger number of customers to serve forces them to roll-out a network with a larger number of base stations. As a result, the cost saving associated with the access to a larger amount of spectrum per sector (allowing to roll-out less base stations as a consequence of the larger cell range per base station) are the highest and make these operators the major applicants of additional radio spectrum.

- Similarly, the entrant is a leading candidate to give up spectrum. The smaller number of customers to attend makes them roll out a network with a smaller number of base stations (comparatively with the network of the rest of operators). Consequently, their cost increases due to the roll-out of their network with a lower spectrum bandwidth are lower than the savings earned by other operators.

- The largest cost savings occur when moving from 5MHz/sector to 10MHz/sector (see Table 26). As a result, virtually in all cases, an operator with a 5MHz/sector spectrum assignment would find some operator with more than 10MHz/sector willing to give up 5MHz/sector. Moreover, in those cases the acquisition of additional 5MHz/sector means making the business model viable as it can be seen in Table 24 (IRR>15%). For the same reason, operators with an assignment of 10MHz/sector are the least prone to participate in the secondary spectrum market as a seller/lessee (the release of 5MHz/sector means a large increase in network roll-out costs as it can be seen in Table 25).

- Finally and as an example, the results obtained in the case of considering a new entrant with 15MHz/sector and with 20MHz/sector as the seller/lessee operator are presented graphically in Figure 24 and in Figure 25 and numerically in Table 28.

Buyers		Seller: New entrant (15 MHz/sector to 10)			Seller: New entrant (20 MHz/sector to 15)		
		Min	Max	Mean	Min	Max	Mean
New entrant	5 to 10MHz/sector	226.6 €	946.6 €	586.6 €	177.1 €	946.6 €	561.8 €
	10 to 15MHz/sector	226.6 €	226.6 €	226.6 €	177.1 €	226.6 €	201.9 €
	15 to 20MHz/sector	*	*	*	177.1 €	177.1 €	177.1 €
Medium operator	5 to 10MHz/sector	226.6 €	1,503.9 €	865.3 €	177.1 €	1,503.9 €	840.5 €
	10 to 15MHz/sector	226.6 €	415.5 €	321.0 €	177.1 €	415.5 €	296.3 €
	15 to 20MHz/sector	226.6 €	374.3 €	300.4 €	177.1 €	374.3 €	275.7 €
Incumbent	5 to 10MHz/sector	226.6 €	2.278.3 €	1,252.5 €	177.1 €	2,278.3 €	1,227.7 €
	10 to 15MHz/sector	226.6 €	479.9 €	353.3 €	177.1 €	479.9 €	328.5 €
	15 to 20MHz/sector	226.6 €	736.8 €	481.7 €	177.1 €	736.8 €	456.9 €

Table 28. Minimum, median and maximum price (in m€) considering a new entrant as a seller/lessee operator in the case of urban areas

(* Maximum price the buyer/lessor is willing to pay is less than minimum price the seller/lessee is willing to obtain, therefore the transaction cannot take place)

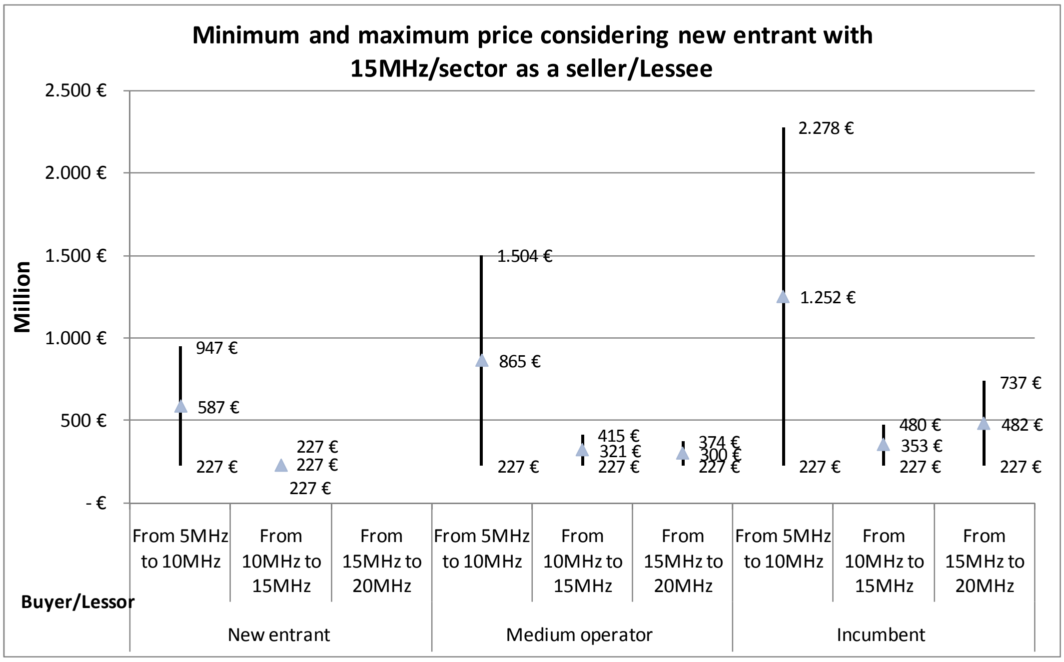

Figure 24. Minimum, median and maximum price considering a new entrant with 15MHz/sector as a seller/lessee operator in the case of urban areas

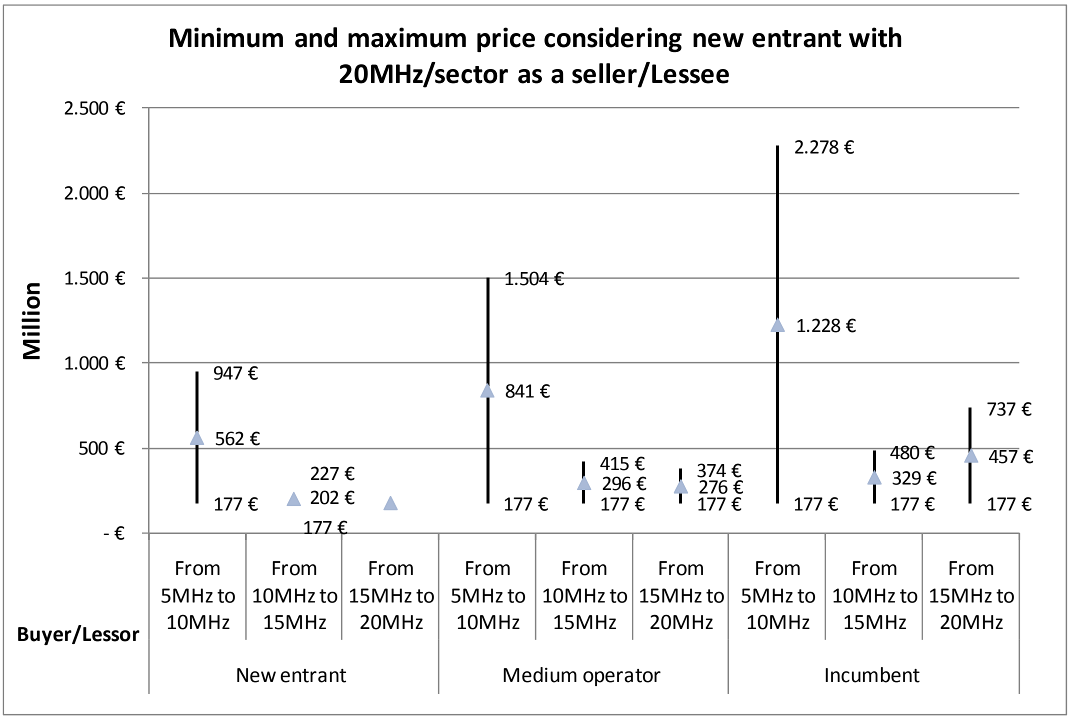

Figure 25. Minimum, median and maximum price considering a new entrant with 20MHz/sector as a seller/lessee operator in the case of urban areas

In the two previous cases and as observed in the correspondent figures, a new entrant with an assignment of 15MHz/sector or 20MHz/sector would be willing to sell 5MHz/sector and that spectrum would be acquired by the operator willing to pay more for it. According to the values obtained, this would be, the 5MHz/sector operators (ordered in incumbent, medium and new entrant), then the incumbent operator with 15MHz/sector.

6.7.4.2 Case 2: Suburban areas

In this section, the results obtained in the case of suburban areas are presented. The methodology used to get the results is the same presented for the urban areas. Table 29 and Table 30 show the net present values (NPV) after ten years and the Internal Rate of Return (IRR) for the different mobile operators and spectrum assignments considered.

NPV	5 MHz/sector	10 MHz/sector	15 MHz/sector	20 MHz/sector
New entrant	- 2.227,755 €	- 634,382 €	- 177,260 €	- 44,806 €
Medium operator	- 2.276,95 €	397,07 €	1.193,08 €	1.331,51 €
Incumbent	- 2.355,12 €	1.414,60 €	2.347,01 €	2.766,40 €

Table 29. NPV after 10 years for the different mobile operators and spectrum assignments considered in suburban areas

IRR	5 MHz/sector	10 MHz/sector	15 MHz/sector	20 MHz/sector
New entrant	-		10,40%	13,88%
Medium operator	-	21,20%	37,03%	39,56%
Incumbent	-	32,36%	45,66%	52.69%

Table 30. IRR for the different mobile operators and spectrum assignments considered in suburban areas

By comparison of the network costs for the different spectrum assignments and operators, the radio spectrum supply and demand in the secondary market can be obtained following the methodology described in the case of urban areas. Taking into consideration spectrum supply and demand, the combinations in which there could be a transaction of spectrum are presented in Table 31. As in the case of urban areas, among all the possible combinations, the transaction would only make economic sense if the maximum price willing to pay for the buyer/lesser operator is greater than or equal to the minimum price fixed by the seller/lessee operator. The possible combinations for the radio spectrum transaction are shown in green on the table and the average price corresponding to those minimum and maximum prices is included. The combinations for the radio spectrum transaction that do not make sense are shown in red and do not include any numbers.

As shown in the table, the players of most of transactions are an operator with an assignment of 20MHz/sector as a seller/lessee and an operator with an assignment of 5MHz/sector as a buyer/lessor. Likewise, and as in the case of urban areas, the largest number of potential transactions involves a new entrant as a seller/lessee.

Buyer/Lessor		Seller/Lessee: New entrant 10-5 MHz/sec	New entrant 15-10 MHz/sec	New entrant 20-15 MHz/sec	Medium operator 10-5 MHz/sec	Medium operator 15-10 MHz/sec	Medium operator 20-15 MHz/sec	Incumbent operator 10-5 MHz/sec	Incumbent operator 15-10 MHz/sec	Incumbent operator 20-15 MHz/sec
New entrant	5-10 MHz/sect	1.593 €	1.025 €	863 €		1.195 €	866 €		1.263 €	1.006 €
	10-15 MHz/sect		457 €	295 €			298 €			438 €
	15-20 MHz/sect			132 €						
Medium operator	5-10 MHz/sect	2.134 €	1.566 €	1.403 €	2.674 €	1.735 €	1.406 €		1.803 €	1.547 €
	10-15 MHz/sect		627 €	464 €		796 €	467 €			608 €
	15-20 MHz/sect			135 €			138 €			
Incumbent operator	5-10 MHz/sect	2.682 €	2.113 €	1.951 €	3.222 €	2.283 €	1.954 €	3.770 €	2.351 €	2.095 €
	10-15 MHz/sect		695 €	532 €		864 €	535 €		932 €	676 €
	15-20 MHz/sect			276 €			279 €			419 €

Table 31. Potential transactions of 5MHz/sector among the mobile operators considered in suburban areas and their average prices in m€

Finally, the results obtained in the case of considering a new entrant with 15MHz/sector and with 20MHz/sector as the seller/lessee operator are presented graphically in Figure 26 and in Figure 27. The same consideration made for urban areas could be also made from these figures.

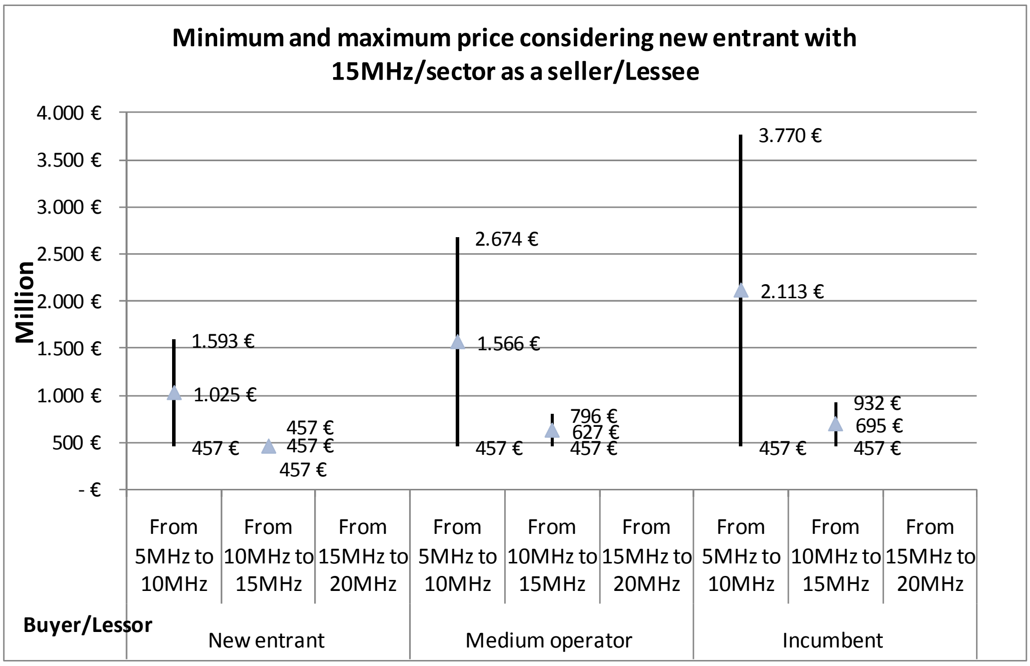

Figure 26. Minimum, median and maximum price considering a new entrant with 15MHz/sector as a seller/lessee in the case of suburban areas

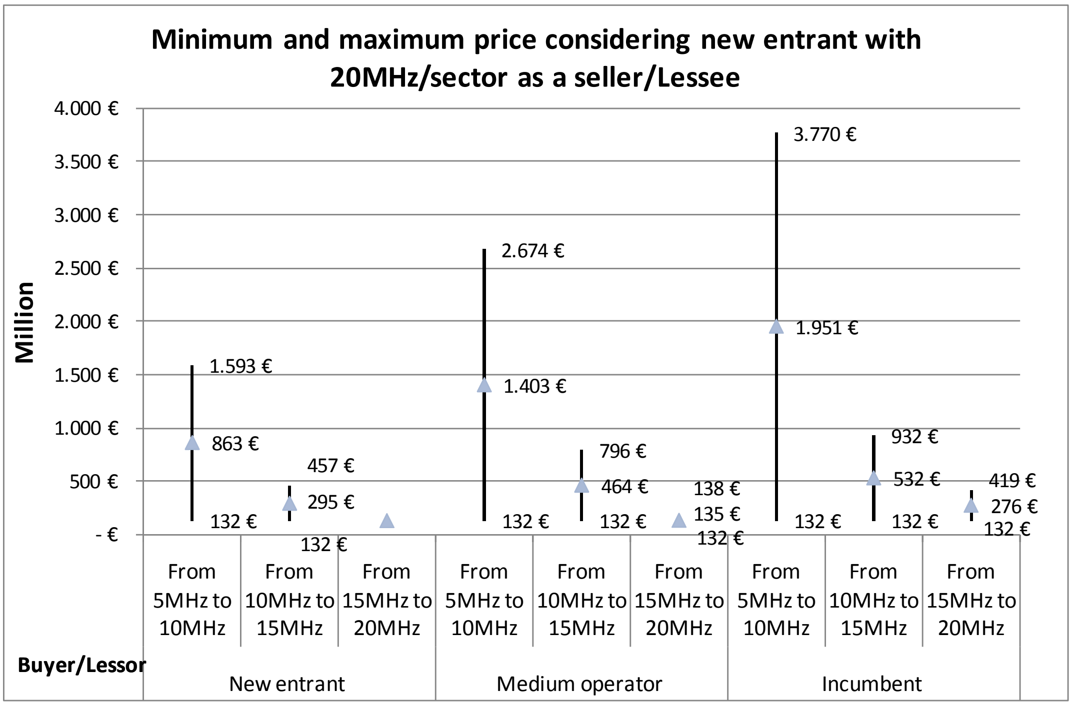

Figure 27. Minimum, median and maximum price considering a new entrant with 20MHz/sector as a seller/lessee operator in the case of suburban areas

6.7.4.3 Case 3: Rural

Similarly, the results obtained in the case of rural areas are presented below.

NPV after 10 years	5MHz/sector	10MHz/sector	15MHz/sector	20MHz/sector
New entrant	- 8.342,994 €	- 7.975,127 €	- 4.106,107 €	- 4.069,768 €
Medium operator	- 5.516,54 €	- 4.226,84 €	469,24 €	497,21 €
Incumbent	- 2.906,31 €	250,12 €	4.475,49 €	4.586,92 €

Table 32. NPV after 10 years for the different mobile operators and spectrum assignments considered in rural areas

IRR	5MHz/sector	10MHz/sector	15MHz/sector	20MHz/sector
New entrant	-	-	.	.
Medium operator	-	-	17,67%	17,83%
Incumbent	3,02%	16,15%	38,78%	39,19%

Table 33. IRR for the different mobile operators and spectrum assignments considered in rural areas

A differential feature of the rural case regarding the urban and suburban ones is that the business model is profitable only in a small number of situations as it is shown in IRR table above. As a result, there might be situations where an operator that has a radio spectrum resource assignment in a national scale may decide not to deploy its network in some rural areas due to an insufficient economic return. In that case, this operator may be interested in getting some return on the investment made in the acquisition of that spectrum by selling or leasing it to another operator in these rural areas. In this situation, the minimum price for these transactions could be considered equal to 0 € and transactions involving a higher amount of spectrum (higher than the 5MHz/sector considered in the urban and suburban areas) could make sense since the operator could simply decide not to roll out its network. Therefore, the results obtained in the case of transactions of 5MHz/sector and 10MHz/sector are presented in the case of rural areas.

In the case of urban and suburban areas, the basic assumption is the operator roll out its own network and transaction of radio spectrum involving more than the 5MHz/sector would be unlikely because this implies to provide to another operator most of their own radio spectrum resources.

Table 34 shows the possible transactions of 5MHz/sector that could occur based on the configuration of radio spectrum supply and demand. As in the case of the aforementioned areas, among all the possible combinations, the transaction would only make economic sense if the maximum price willing to pay for the buyer/lessor operator is greater than or equal to the minimum price fixed by the seller/lessee operator. The colours and numbers used in the table have the same meaning as the ones explained in urban and suburban areas.

		Seller/Lessee								
Buyer/Lessor		New entrant			Medium operator			Incumbent operator		
		10-5 MHz/sec	15-10 MHz/sec	20-15 MHz/sec	10-5 MHz/sec	15-10 MHz/sec	20-15 MHz/sec	10-5 MHz/sec	15-10 MHz/sec	20-15 MHz/sec
New entrant	5-10 MHz/sect	368 €		202 €			198 €			240 €
	10-15 MHz/sect	2.118 €	3.869 €	1.953 €	2.579 €		1.948 €	3.513 €		1.990 €
	15-20 MHz/sect			36 €			32 €			
Medium operator	5-10 MHz/sect	829 €		663 €	1.290 €		659 €			701 €
	10-15 MHz/sect	2.532 €	4.283 €	2.366 €	2.993 €	4.696 €	2.362 €	3.926 €	4.461 €	2.404 €
	15-20 MHz/sect						28 €			
Incumbent operator	5-10 MHz/sect	1.762 €		1.596 €	2.223 €		1.592 €	3.156 €		1.634 €
	10-15 MHz/sect	2.297 €	4.047 €	2.131 €	2.758 €		2.127 €	3.691 €	4.225 €	2.168 €
	15-20 MHz/sect			74 €			70 €			111 €

Table 34. Potential transactions of 5MHz/sector among the mobile operators considered in rural areas and their average prices in m€

The main difference from previous cases is that, in this case, most of transactions involve an operator with an assignment of 10MHz/sector as a buyer/lessor. The reason is that the cost saving associated with growing from 15MHz/sector to 20MHz/sector are very low (as it can be observed in data from Table 32) as a consequence of the lower traffic level present in the rural areas compared with that of urban or suburban areas. For the same reason, in almost all cases, an operator with 20MHz/sector in a rural area would be willing to supply 5MHz/sector in the secondary market.

Finally, the results obtained in the case of a new entrant with 10MHz/sector and with 20MHz/sector as the seller/ lessee operator are presented graphically in Figure 28 and in Figure 29. The same consideration made for urban areas could be also made from these figures.

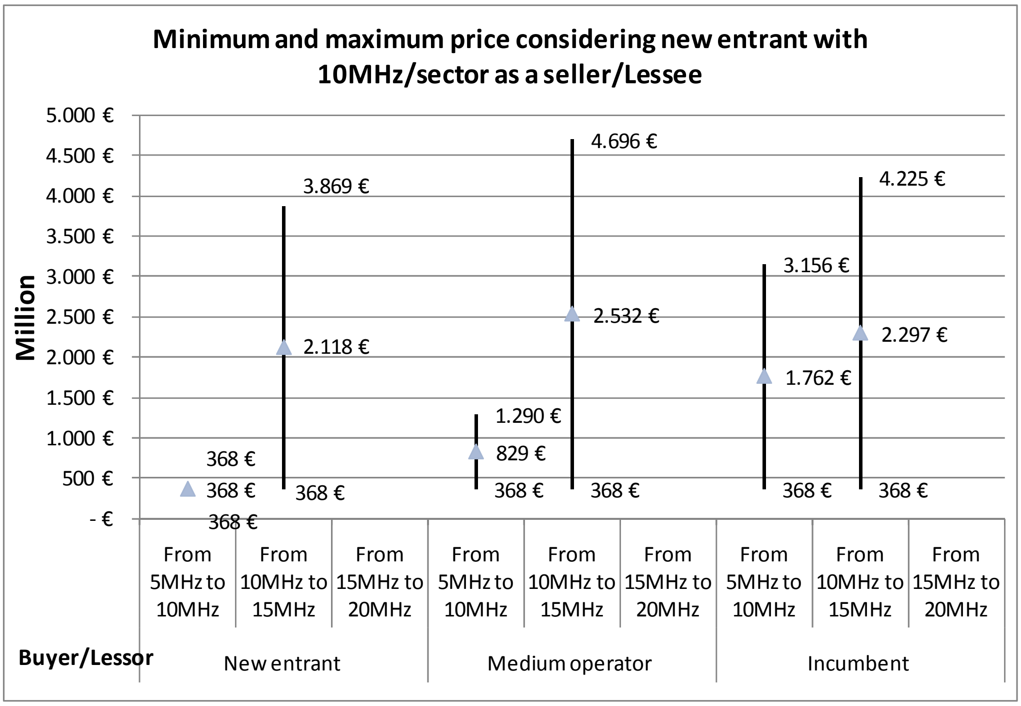

Figure 28. Minimum, median and maximum price considering a new entrant with 10MHz/sector as a seller/lessee operator in the case of rural areas (5MHz/sector transaction)

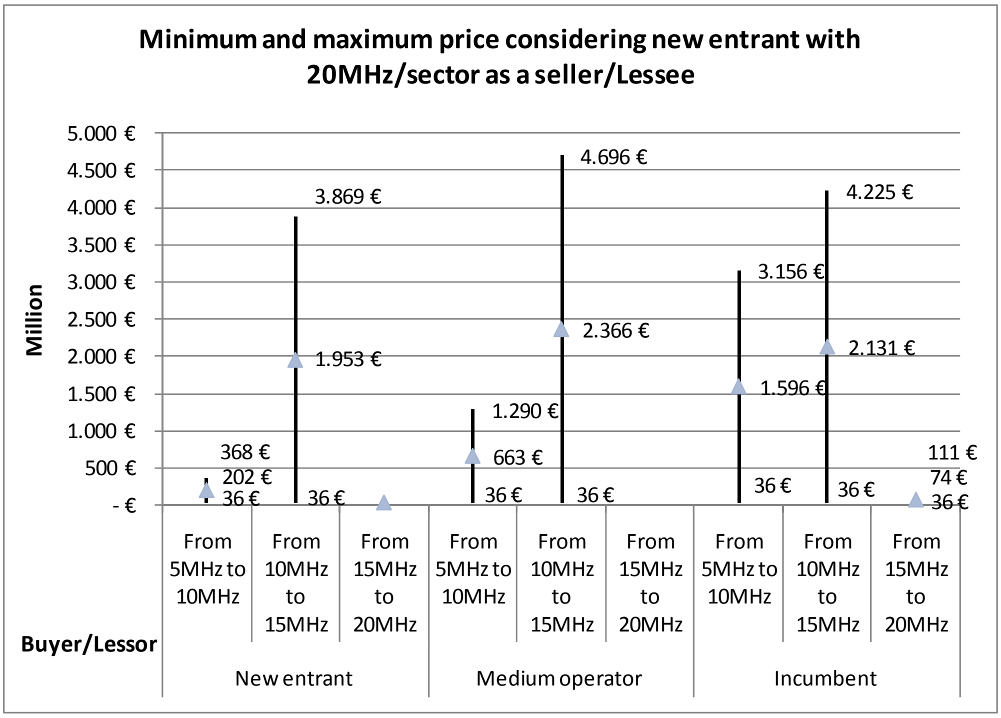

Figure 29. Minimum, median and maximum price considering a new entrant with 20MHz/sector as a seller/lessee operator in the case of rural areas (5MHz/sector transaction)

Table 35 shows the potential transactions of 10MHz/sector that could take place among the different operators and spectrum assignment considered. Only operators that already own spectrum are considered (i.e. transactions from 0 to 10 MHz/sector are not contemplated). The case of a seller/lessee going from 10MHz/sector to 0MHz/sector corresponds to an operator that decides not to deploy the network in the rural area.

Buyer/Lessor		Seller/Lessee								
		New entrant			Medium operator			Incumbent operator		
		10MHz-0MHz	15MHz-5MHz	20MHz-10MHz	10MHz-0MHz	15MHz-5MHz	20MHz-10MHz	10MHz-0MHz	15MHz-5MHz	20MHz-10MHz
New entrant	5MHz-15MHz	2.118 €	4.237 €	4.071 €	2.118 €			2.118 €		
	10MHz-20MHz	1.953 €		3.905 €	1.953 €			1.953 €		
Medium operador	5MHz-15MHz	2.993 €	5.111 €	4.946 €	2.993 €	5.986 €	5.355 €	2.993 €		5.161 €
	10MHz-20MHz	2.362 €	4.480 €	4.315 €	2.362 €		4.724 €	2.362 €		4.530 €
Incumbent operator	5MHz-15MHz	3.691 €	5.809 €	5.644 €	3.691 €	6.684 €	6.053 €	3.691 €	7.382 €	5.859 €
	10MHz-20MHz	2.168 €	4.287 €	4.121 €	2.168 €			2.168 €		4.337 €

Table 35. Potential transactions of 10MHz/sector among the mobile operators considered in rural areas and their average prices in m€

As it can be seen from table above, the radio spectrum supply is determined mainly by mobile operators that decide not to deploy in rural areas and have a spectrum assignment of 10MHz/sector. In the rest of cases where the transaction is possible, the seller/lessee operator is a new entrant. In terms of demand, this is set largely for the medium and incumbent operators with 5MHz/sector.

Therefore, it is considered quite likely that if there is a new entrant and one or more medium or incumbent operators in the market, the entrant may not get to deploy (at least initially) in rural areas because of the lack of profitability, and find in the provision of such resources to other operators in the secondary market an acceptable return on the investment made in acquiring the radio spectrum licence. This transfer would also ensure to the medium or incumbent operators that their network rollouts in rural areas are profitable.

6.7.4.4 Result comparison among the different geographic areas

Finally, a comparison of average prices of the transactions in the different geographical areas is presented in Table 36 and Table 37 weighted by the area of coverage.

Table 36 represents the ratio between the average prices per area of the transactions in the suburban areas (calculated from average prices presented in Table 31 adjusted by the total area of coverage in suburban areas, 16,433 km^2 according to Table 1) and the average prices per area of the transactions in the urban areas (following the same process but taken average prices from Table 27 and an area of coverage of 1,952km^2).

Table 37 represents the ratio between the average prices per area of the transactions in the rural areas (calculated from average prices presented in Table 34 adjusted by the total area of coverage in rural areas, 282,412 km^2 according to Table 1) and urban areas.

Buyer/Lessor		Seller/Lessee: New entrant 10-5 MHz/sec	New entrant 15-10 MHz/sec	New entrant 20-15 MHz/sec	Medium operator 10-5 MHz/sec	Medium operator 15-10 MHz/sec	Medium operator 20-15 MHz/sec	Incumbent operator 10-5 MHz/sec	Incumbent operator 15-10 MHz/sec	Incumbent operator 20-15 MHz/sec
New entrant	5-10 MHz/sect	20%	21%	18%		21%	16%		21%	14%
	10-15 MHz/sect		24%	17%						
	15-20 MHz/sect			9%						
Medium operator	5-10 MHz/sect	21%	21%	20%	21%	21%	18%		22%	16%
	10-15 MHz/sect		23%	19%		23%	14%			
	15-20 MHz/sect			6%			4%			
Incumbent operator	5-10 MHz/sect	20%	20%	19%	20%	20%	18%	20%	20%	17%
	10-15 MHz/sect		23%	19%		23%	15%		23%	
	15-20 MHz/sect			7%			6%			7%

Table 36. Comparison of average prices of the transactions (in €/MHz/km^2) in the suburban and urban areas

Buyer/Lessor		Seller/Lessee: New entrant 10-5 MHz/sector	New entrant 15-10 MHz/sector	New entrant 20-15 MHz/sector	Medium operator 10-5 MHz/sector	Medium operator 20-15 MHz/sector	Incumbent 20-15 MHz/sector
New entrant	5-10 MHz/sector	0,3%		0,2%		0,2%	0,2%
	10-15 MHz/sector		11,8%	6,7%			
	15-20 MHz/sector			0,1%			
Medium operator	5-10 MHz/sect	0,5%		0,5%	0,6%	0,5%	0,4%
	10-15 MHz/sector		9,2%	5,5%		4,1%	
	15-20 MHz/sector					0,1%	
Incumbent operator	5-10 MHz/sector	0,8%		0,9%	0,8%	0,8%	0,7%
	10-15 MHz/sector		7,9%	4,5%		3,4%	
	15-20 MHz/sector			0,1%		0,1%	0,1%

Table 37. Comparison of average prices of the transactions (in €/MHz/km^2) in the rural and urban areas

As it can be seen from Table 36 and Table 37 above (in the cases where the transactions have economic sense and an average price can be obtained), the weighted average price of transactions in suburban areas are between 6% and 23% of the price in urban areas.

In the case of rural areas, those prices would range between 1% and 12%. These higher prices in urban areas can be explained in base of the higher density of population that makes these areas more profitable for the provision of these services increasing the value of the spectrum.

6.8 ROCKET business case results: Relay-based Deployment

This section evaluates the economical feasibility of a 4G relay-based deployment, by the evaluation of the EBITDA and NPV with time, on a period of 10 years. The technical inputs of the model are the cell sizes and the number of required RS per sector, and have been obtained according to the indifference plots methodology described in [27] considering the outage service and average traffic defined in Table 6 and Table 16 respectively. Results are obtained assuming both ROCKET and FIREWORS relay-operating conditions and configurations, so that specific system design recommendations can be derived.

6.8.1 Comparison between relay-based and non relay-based architectures

A general consideration that has to be done in the interpretation of these results is that the same cost of the terminal has been assumed in all cases. As a consequence and taken into account that terminals with a single antenna (as those used in “No relaying – 2×1”, “Protocol III – 2×2×1”, AF-Full Duplex – 2×2×1 and “TWRC Prot I – 2×2×1”) could be cheaper than those with multiple antennas, the economic results for these cases with a single antenna user terminals should be slightly better than the ones presented in this section (the terminal subsidy policy, included as the concept “Subscriber Acquistion and retention costs”, is one of the main contributors to the accumulated OPEX representing the 20% of the total OPEX in the base case; see Figure 17).

6.8.1.1 Number of base stations and relays base stations

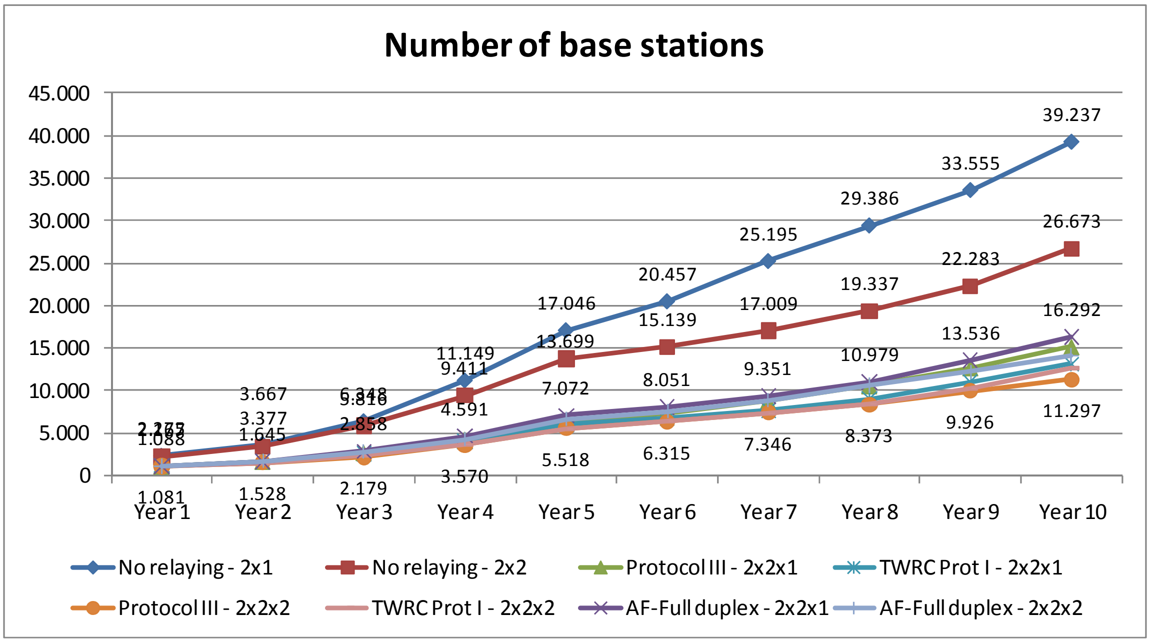

Figure 30. Number of BS deployed over 10 years for the different relaying protocols and antenna configurations

Figure 30 shows that the network without relays requires considerably more base stations than the network with relays, as a result of the enhanced spectral efficiency and more homogeneous coverage provided by relayed transmissions. A higher number of antennas also reduces the number of BS, thus showing the complementarity of MIMO and relaying technologies. The smallest number of BS is reached when Protocol III is chosen.

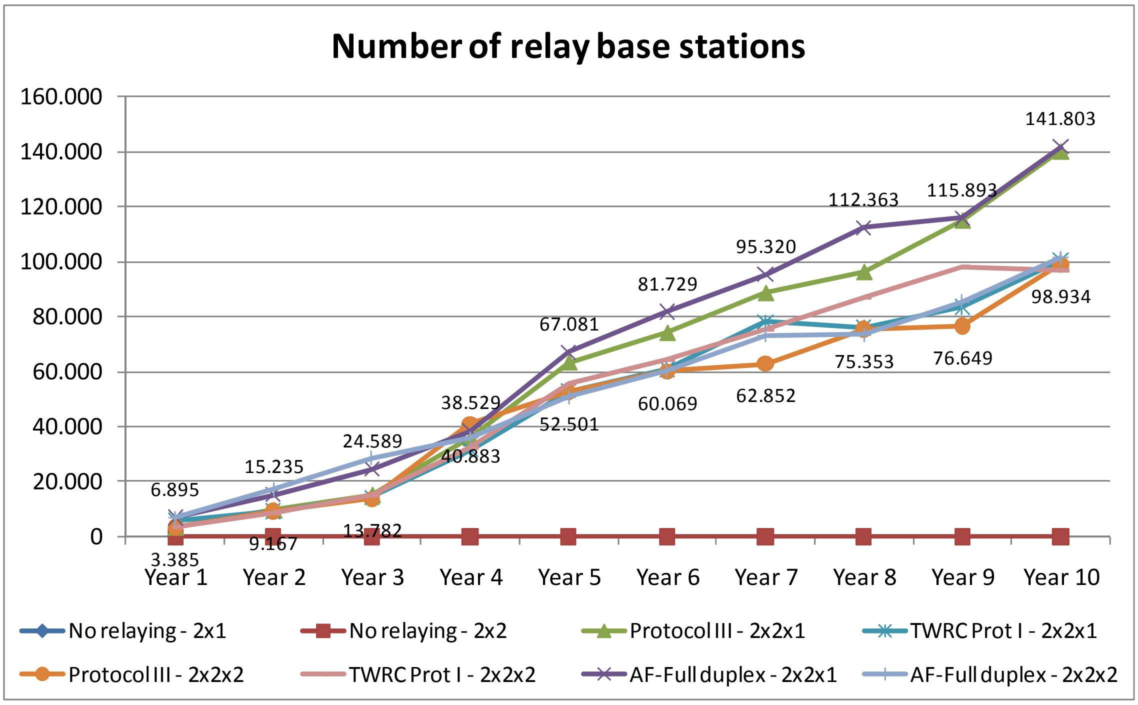

Figure 31. Number of RS deployed over 10 years for the different relaying protocols and antenna configurations

Figure 31 shows that a higher number of antennas reduces also the number of relays needed. The smallest number of relays is reached for Protocol III and AF-FullDuplex relaying. In all cases, the system simulator also provided the optimum position of the RS in the cell, which was consistently found to be between 65% and 75% of the cell radius.

6.8.1.2 CAPEX

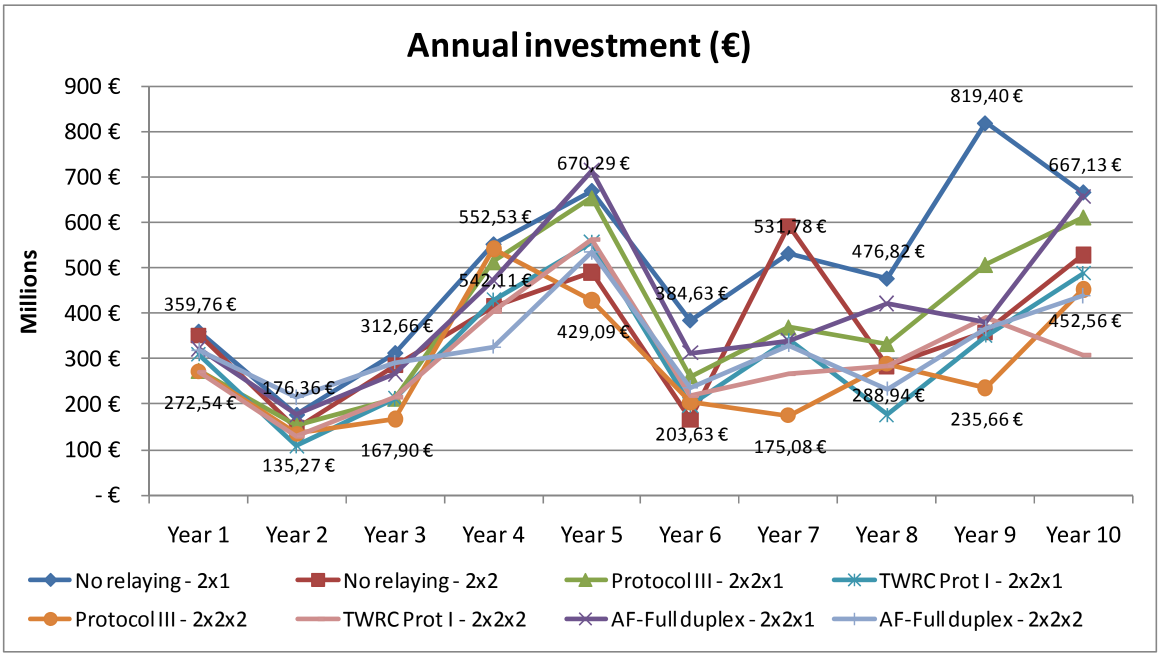

Figure 32. Annual capital investment over 10 years for the different relaying protocols and antenna configurations

As it can be seen in Figure 32, a relevant increase of the investment is needed in year 7 and year 9 in the case of “No relaying -2×2” and “No relaying – 2×1”. Those increases are not related with an increase in the number of base stations (see Figure 30) but with the necessity of increasing the bit rate of most base stations as a result of the traffic demands. Concretely, the traffic demand from users make it necessary to update most microwave backhaul lines from E3 (34Mbps) to STM-1 (155Mbps) in those cases. (The cost of a STM1 deployment may be 3 times as high as that of an E3). The accumulated CAPEX for the different protocols and configurations is shown in Figure 33.

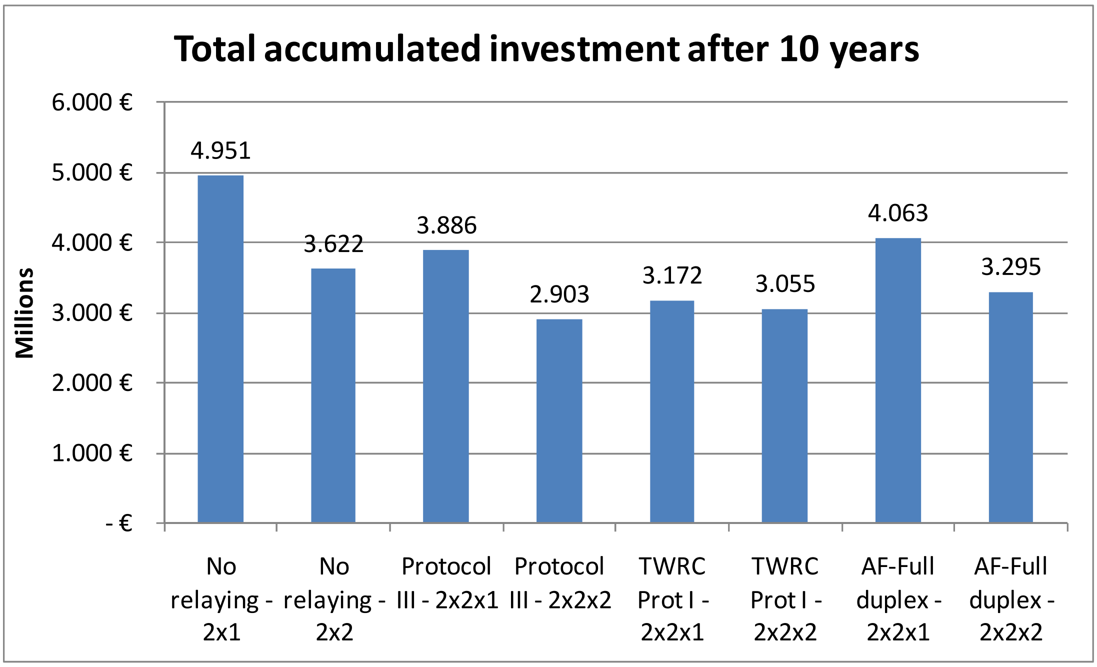

Figure 33. Total accumulated capital investment for the different relaying protocols and antenna configurations

6.8.1.3 OPEX

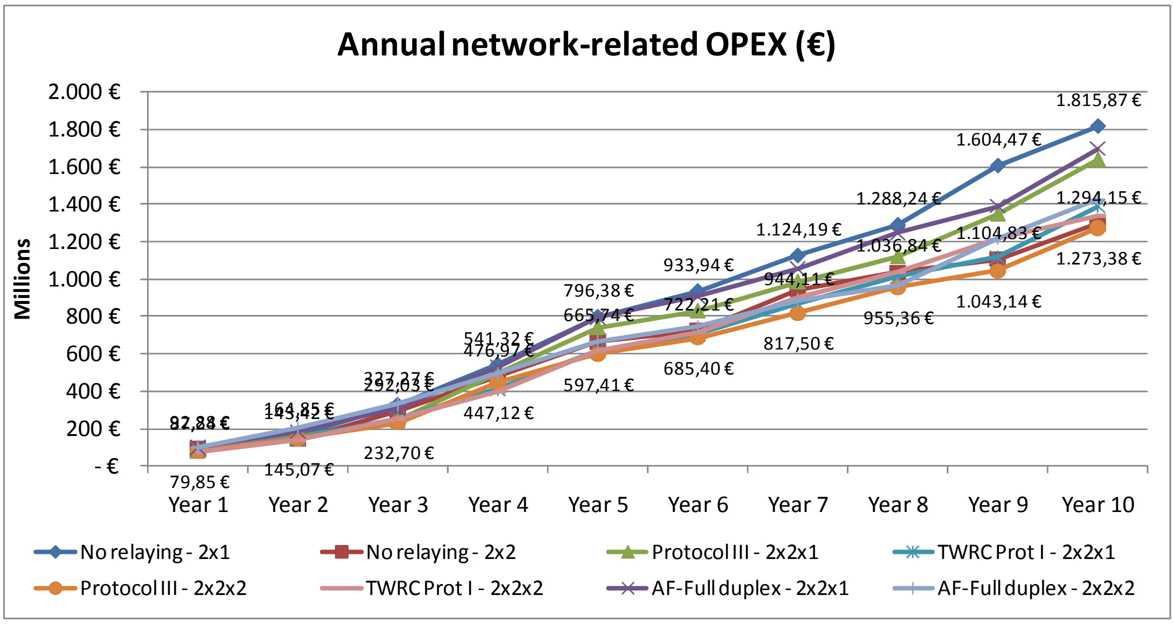

Figure 34. Annual network-related OPEX over 10 years and antenna configurations

In Figure 34, it can be appreciated that the network without relay has a bigger OPEX than the network with relays. Furthermore, the difference between the no relay and relay networks in terms of OPEX increases with time. The accumulated OPEX for the different protocols and configurations is shown in Figure 35.

Again, the costs associated to OPEX are lower for relay-based deployments based in Protocol III. As said before, the difference of terminal costs due to a higher number of antennas has not been considered in the model and would slightly increase the OPEX for the 2×2×2 (in the relay-based deployment) and for the 2×2 (in the non relay-based deployment) cases. Still, the conclusions in terms of difference between CAPEX and OPEX would remain the same.

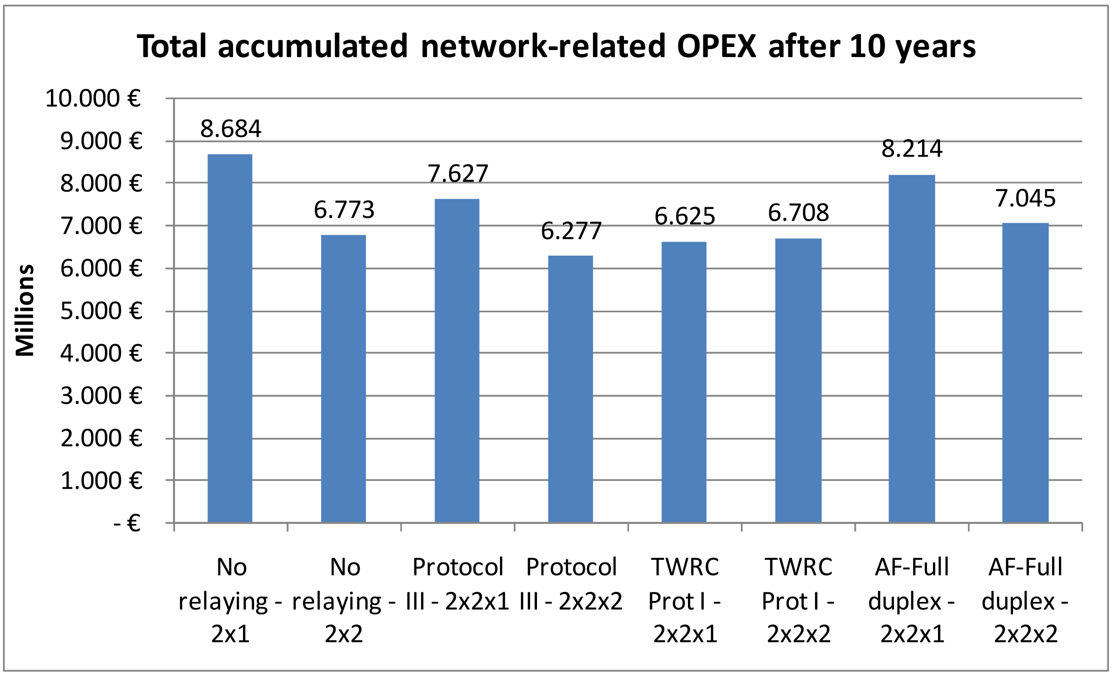

Figure 35. Total accumulated network-related OPEX for the different relaying protocols and antenna configurations

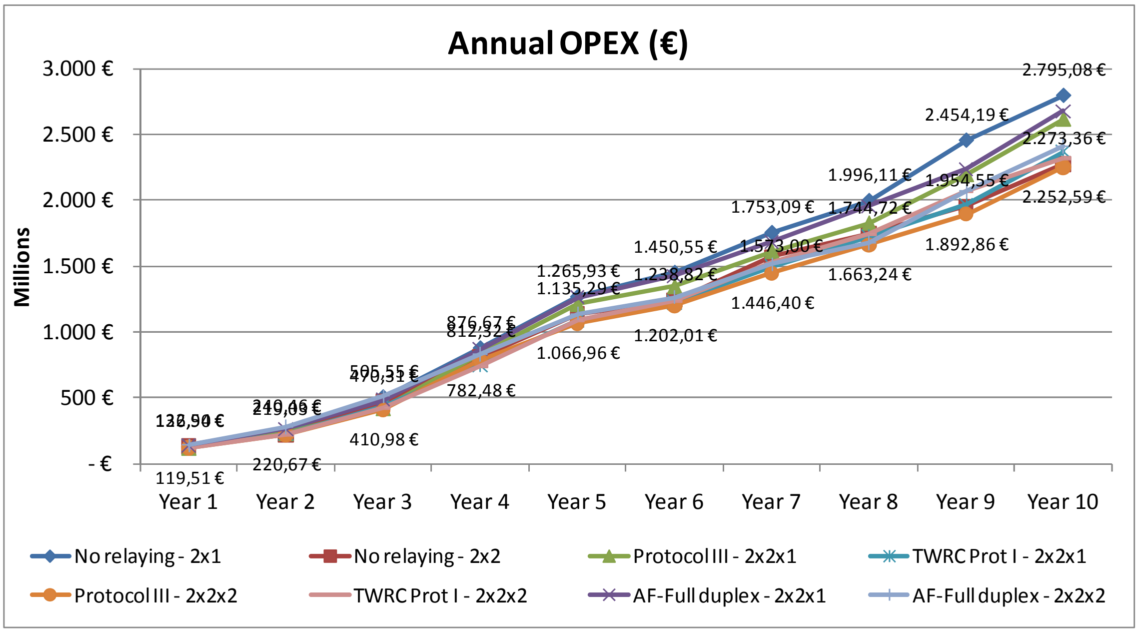

Figure 36. Total OPEX over 10 years period for the different relaying protocols and antenna configurations

Figure 36 and Figure 37 show the total OPEX, that is, including non-network related OPEX (subscriber acquisition costs, marketing programmes, overheads) for the relay and not relay networks. The assumptions about market penetration being the same in all cases, the conclusions to be drawn remain as in previous plots.

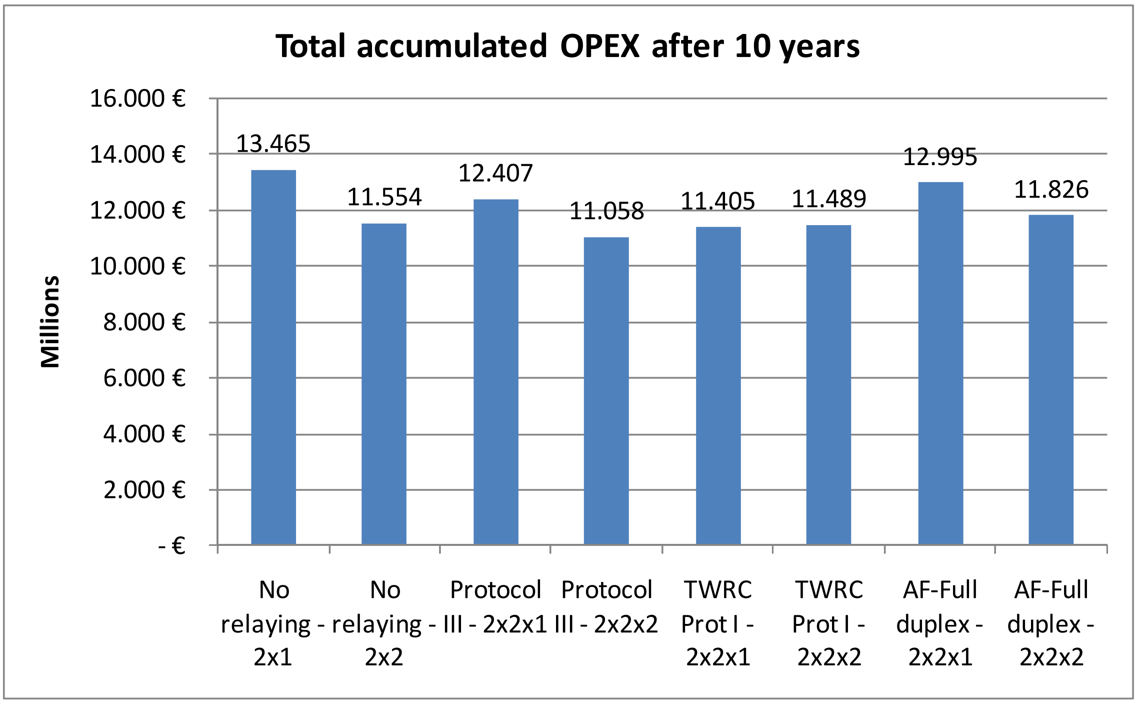

Figure 37. Total OPEX for the different relaying protocols and antenna configurations

6.8.1.4 Base station – relay station cost ratio

It has been mentioned that the cell dimensioning is done based on the most restrictive constrain: either the cell radius that meets the outage service, or the cell radius where spectral efficiency and total traffic meet. It turns out however that the same constraints are present if we simultaneously vary the cell size and the number of relay terminals. As performance improves with the number of RS and the density of BS, we can compensate a decrease in the density of BS by deploying additional RS. This implies that for a given traffic density we may devise multiple solutions involving different densities of BS and RS. The final decision on the cell size and number of relays per cell is taken based on economic aspects which can be parameterised with the BS/RS cost ratio [27]. In all cases studied, and for the period of 10 years, this ratio turned around 7-8. As an example, specific values for the TWRC Prot I relaying protocol are shown in Table 39.

	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10
Number of BS operated	1.075	1.500	2.371	3.634	5.506	6.323	7.339	8.403	10.290	12.612
Number of BS purchased	1.075	425	871	1.263	1.872	817	1.016	1.063	1.887	2.321
BS CAPEX	117,84 €	50,33 €	121,88 €	157,98 €	246,88 €	94,58 €	118,11 €	119,53 €	219,31 €	268,89 €
Cumulative BS CAPEX	117,84 €	168,17 €	290,05 €	448,04 €	694,91 €	789,50 €	907,60 €	1.027,13 €	1.246,44 €	1.515,33 €
BS OPEX	37,51 €	58,55 €	113,30 €	165,84 €	213,73 €	240,50 €	339,10 €	381,61 €	457,60 €	546,87 €
Cumulative BS OPEX	38 €	96 €	209 €	375 €	589 €	829 €	1.169 €	1.550 €	2.008 €	2.555 €
BS cumulative mean cost	**144.507 €**	**176.141 €**	**210.608 €**	**226.507 €**	**233.172 €**	**256.025 €**	**282.871 €**	**306.714 €**	**316.239 €**	**322.712 €**
Number of RS operated	3.225	8.687	14.900	32.710	55.600	64.559	75.234	86.828	98.096	96.831
Number of RS purchased	3.225	5.462	6.213	17.810	22.890	8.959	10.675	11.594	11.267	0
RS CAPEX	42 €	70 €	77 €	218 €	275 €	106 €	125 €	134 €	128 €	- €
Cumulative RS CAPEX	42 €	111 €	189 €	407 €	682 €	789 €	913 €	1.047 €	1.175 €	1.175 €
RS OPEX	19 €	53 €	92 €	206 €	356 €	420 €	497 €	583 €	669 €	680 €
Cumulative RS OPEX	19 €	72 €	165 €	370 €	726 €	1.146 €	1.643 €	2.226 €	2.895 €	3.575 €
RS cumulative mean cost	**19.000 €**	**21.151 €**	**23.726 €**	**23.768 €**	**25.333 €**	**29.961 €**	**33.973 €**	**37.690 €**	**41.494 €**	**49.063 €**
BS/RS cumulated mean ratio	**7,61**	**8,33**	**8,88**	**9,53**	**9,20**	**8,55**	**8,33**	**8,14**	**7,62**	**6,58**

Table 38. Base station to relay station cost ratio

6.8.1.5 Financial results

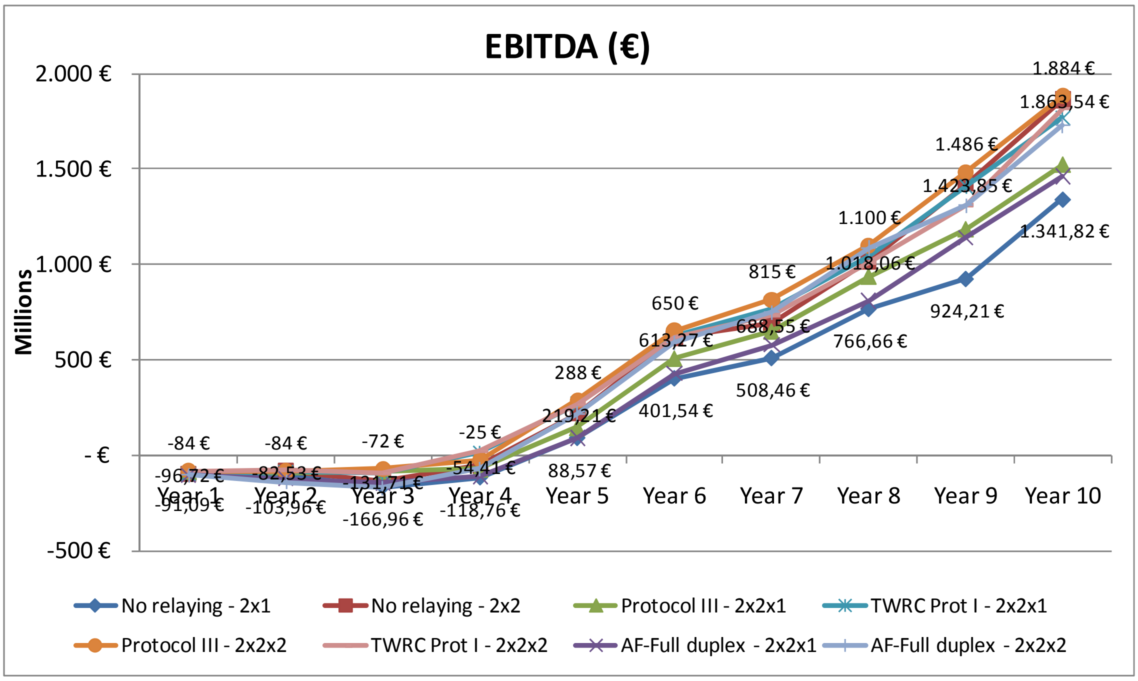

Figure 38. EBITDA over 10 years period for the different relaying protocols and antenna configurations

Figure 38 shows EBITDA comparisons between non-relay and relay networks. From year 4 all relay networks are profitable, whereas non-relay networks become profitable from year 5. Profitability gap between non-relay and relay networks increases with time.

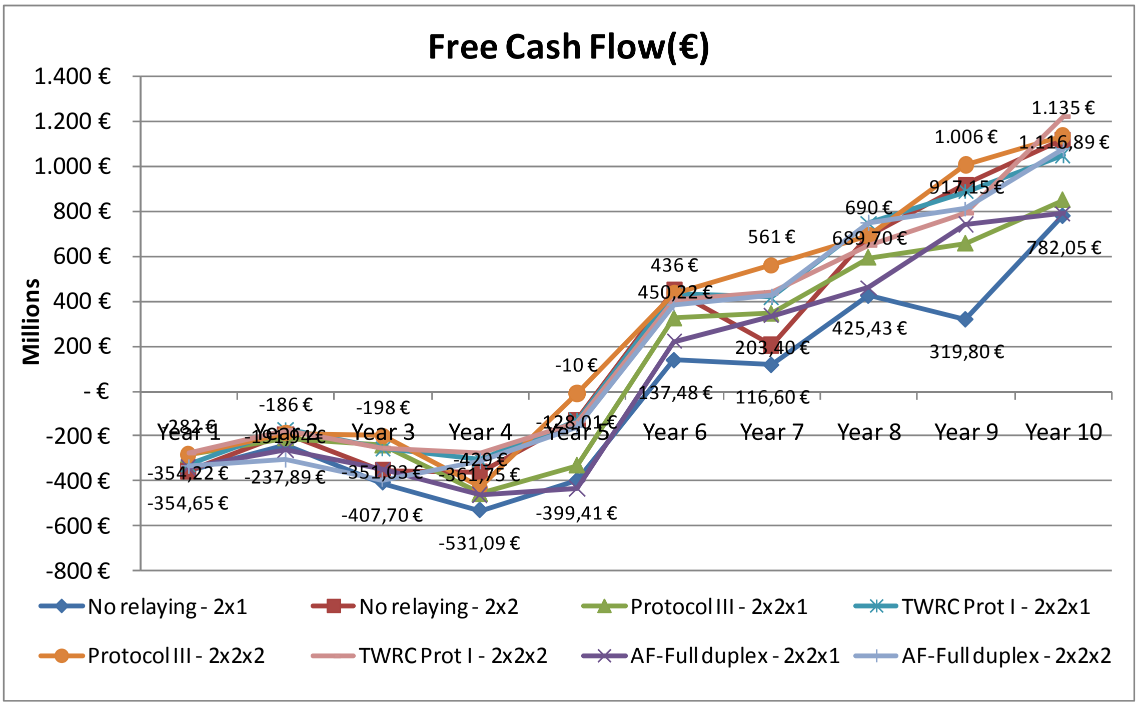

Figure 39. Free cash flow over 10 years period for the different relaying protocols and antenna configurations

Figure 39 shows free cash flow in case of non-relay and relay networks. Relay networks procure a positive free cash flow in year 5, non-relay networks in year 6. There is a significant difference from year 4 to year 6 between relay and non-relay networks' free cash flows.

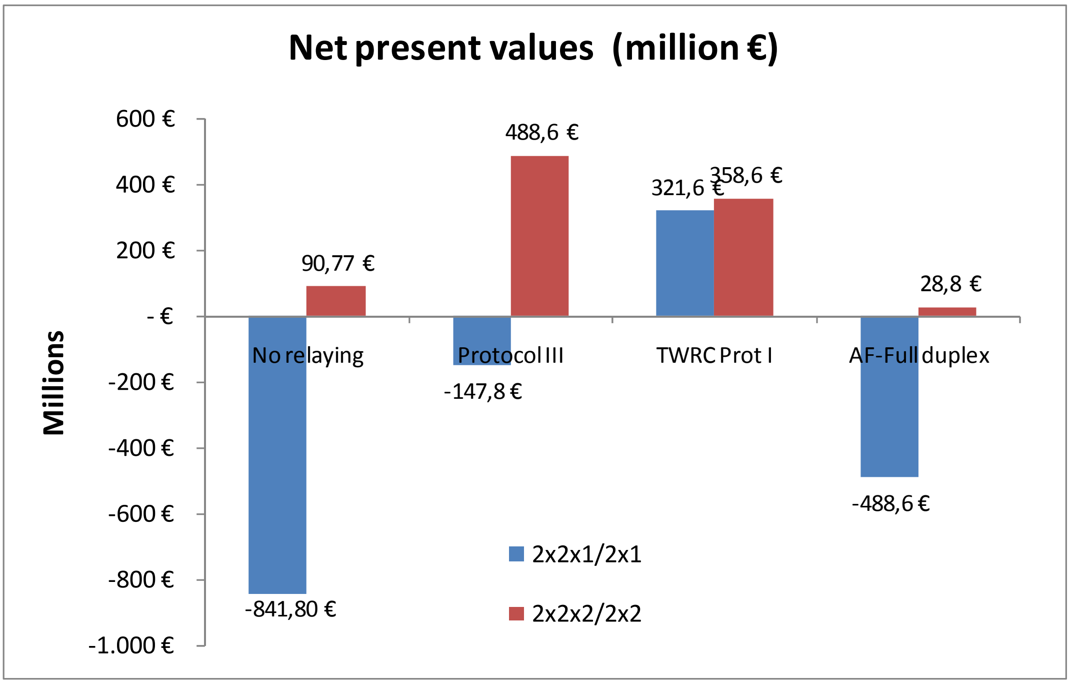

Figure 40. Net present value (in M€) for relaying and non-relaying networks and antenna configurations

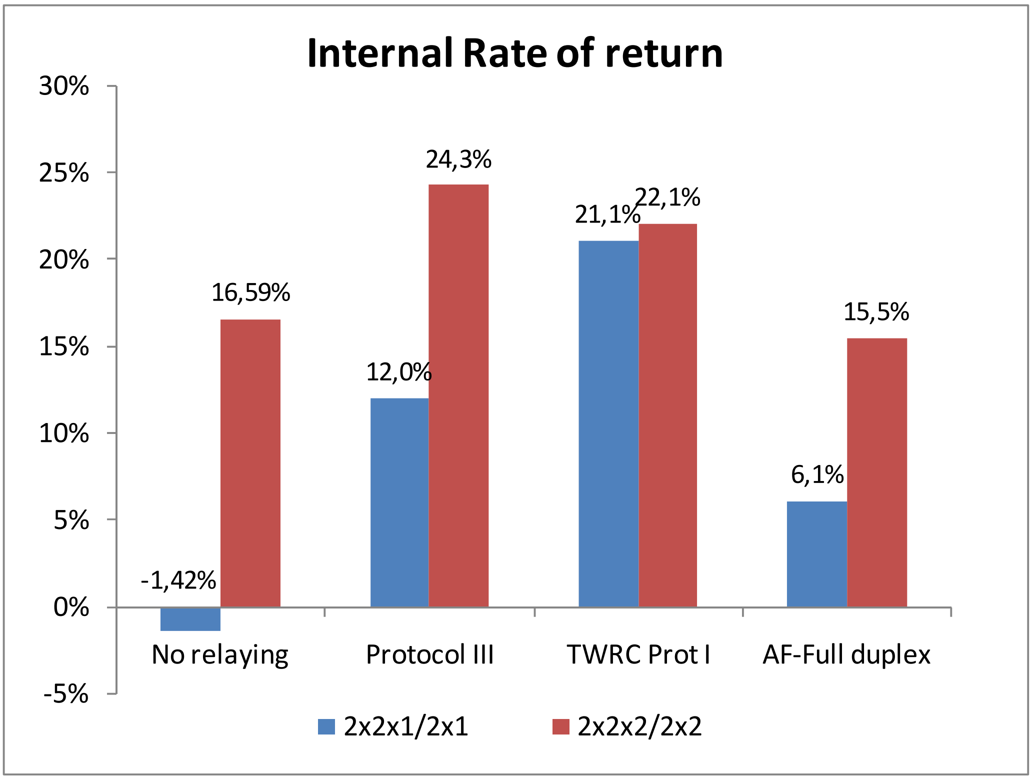

Figure 41. Internal rate of return for relaying and non-relaying networks and antenna configurations

Figures 40 and 41 show the NPV and IRR at year 10. Protocol III achieves a NPV about 1,5 times higher than the next best value. No-relay networks would only become profitable when using at least 2 antennas per terminal.

6.8.2 Comparison between ROCKET and FIREWORKS protocols

Results shown in figures 30 and 31 above seem to indicate that Protocol III would obtain the best economic results, closely followed by TWRC-Prot I. However, it should be stressed that the comparison has not been done under fair conditions of transmitted power. In fact, radiated power for TRWC protocol may be significantly less than in the case of Protocol III (see [27]). For Protocol III, the increased transmission power is efficiently translated into smaller cell sizes, and the radiated power density is still lower for Protocol III than for other protocols (see Table 38).

It should be stressed that, since the model developed in this deliverable assumed the same maintenance cost per BS for both protocols, the effect of total power consumption has not been taken into account. In order to have a more complete picture, future studies should consider this fact.

6.8.3 Radiation density of relay transmissions and human exposure

The ongoing concern about the radiation levels and EM pollution of wireless communications systems might affect the acceptance ratio of relay-based deployments: on one side, the size of cells is larger and hence the number of large BS will decrease, but on the other side, an increased number of RS (although smaller) could generate social concerns. It is however the case that RS can transmit at a lower power since they are in LOS of BS and the pathloss to the assisted MS is smaller (30 dBm have been assumed for RS while 40 dBm have been used for BS). Additionally, to the half-duplex operation of RS, they are not transmitting all the time so the average radiated power is smaller than their maximum nominal power.

In this respect, Table 38 shows the radiated power density (in dBm/Km^2) for different protocols over the 10 years period, for DL (including BS-to-RS/MS and RS-to-MS transmissions) and UL (including MS-to-BS/RS and RS-to-BS transmissions) in the urban scenario (similar conclusions can be derived for suburban and rural). In all cases, the radiated power density for relay-based deployments exhibits a much gentler uptake than for the non-relay network, and after 10 years, the radiated power may have been reduced by 1/3 compared with the relay-based deployment. Notice also that different relay protocols are also emitting different power levels, and that the use of multiple antennas at the MS also reduces significantly the transmitted power density.

Although not specifically proved in this study due to the lack of data on BS and RS power consumptions, these results suggest that relay technologies are also serious candidates for greener wireless network practices.

	DL/UL	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10
No relaying (2×1)	DL	18.7	27.5	54.8	74.3	102.0	138.9	174.2	259.1	308.4	364.3
	UL	14.5	21.1	40.8	55.4	76.0	103.2	131.9	199.5	235.8	276.7
No relaying (2×2)	DL	18.4	22.8	40.4	54.3	70.7	89.2	111.4	173.6	216.5	264.1
	UL	14.9	18.3	31.5	41.9	54.3	68.4	85.0	132.9	166.7	204.0
Prot III (2×2×1)	DL	10.3	13.7	18.0	24.1	30.4	36.6	42.9	69.2	89.8	112.6
	UL	10.4	12.6	16.4	21.4	26.8	31.1	36.4	58.5	74.2	91.9
Prot III (2×2×2)	DL	9.2	10.6	14.9	19.0	27.7	32.8	38.1	51.2	61.2	72.8
	UL	10.0	11.1	14.2	17.9	23.9	28.5	33.5	44.4	52.1	61.3
TWRC (2×2×1)	DL	12.8	13.7	18.2	21.4	26.1	31.9	39.4	68.1	82.0	98.5
	UL	9.1	10.3	14.2	16.7	20.9	25.8	31.7	54.3	65.3	78.4
TWRC (2×2×2)	DL	12.0	12.6	17.3	22.0	25.8	32.0	39.0	61.1	73.9	89.2
	UL	8.4	9.5	13.4	17.7	20.4	25.4	31.0	48.8	59.2	71.9
AF-FD (2×2×1)	DL	10.2	12.7	21.1	26.9	36.5	40.5	50.6	82.7	99.3	119.1
	UL	9.7	11.9	19.0	23.9	32.0	35.7	44.0	71.7	85.8	102.6
AF-FD (2×2×2)	DL	10.0	13.4	22.5	23.4	28.5	35.2	43.2	65.8	79.6	96.3
	UL	9.7	12.8	20.9	21.4	25.4	31.0	37.7	57.1	68.6	82.9

Table 39. DL and UL radiated power density (in dBm/km^2) for non-relay based deployments and for different relay protocols, in urban scenario and 15 MHz bandwidth

6.8.4 Comparison of different bandwidth usage in rural and urban scenarios

As seen in figures 42 and 43, networks with less than 15MHz/sector, and non-relay 2x1 networks are not profitable in any case. At least 15MHz/sector are necessary to achieve profitability in almost all cases.

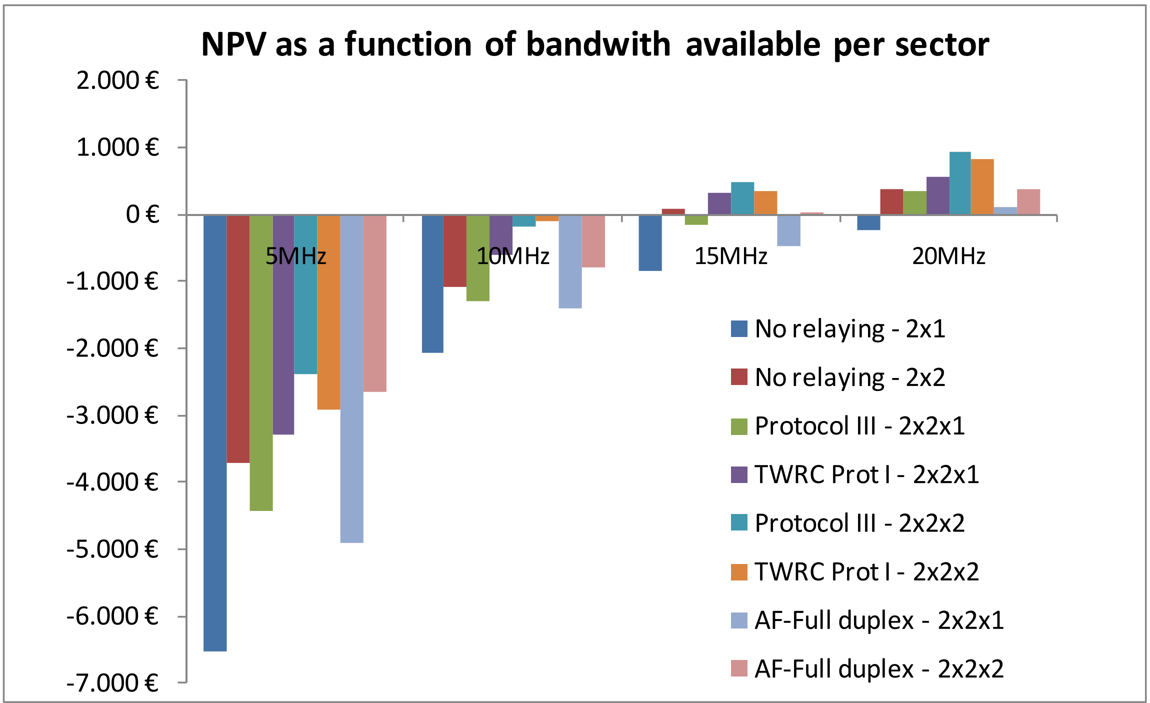

Figure 42. Net present value (in M€) for relaying and non-relaying networks and antenna configurations, depending on the available bandwidth

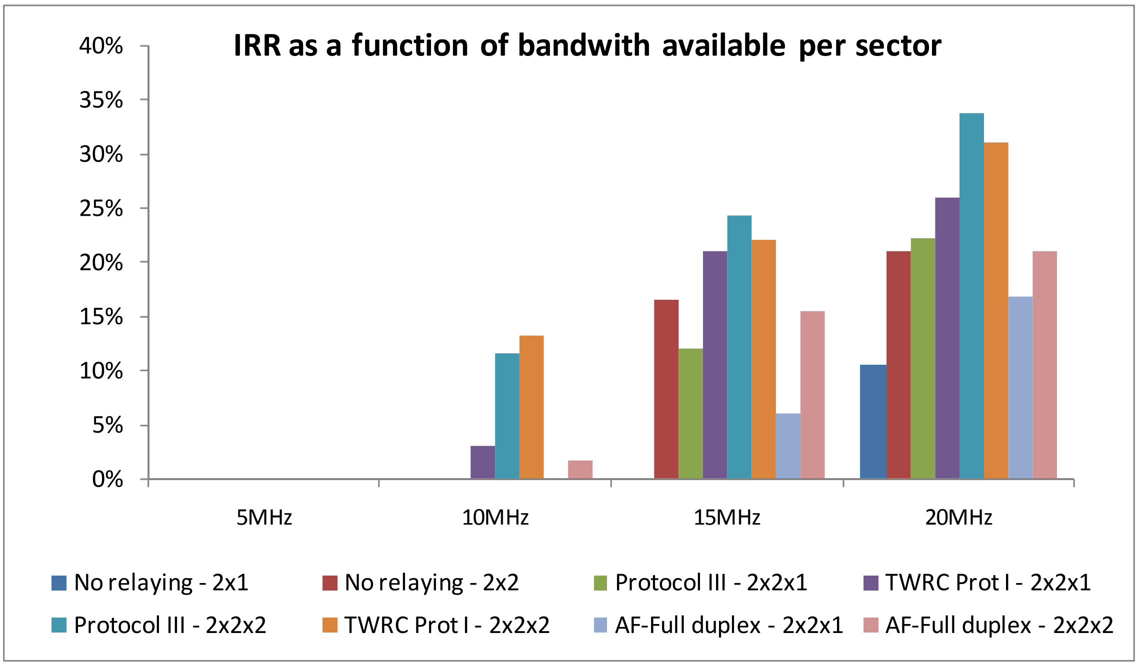

Figure 43. Internal rate of return for relaying and non-relaying networks and antenna configurations, depending on the available bandwidth

In figures 44 and 45, it can be appreciated how the profitability varies with the geographic area considered for a 15MHz/sector network. Rural areas, when considered alone, would yield negative NPVs in all cases. It is important to mention that the NPV is much less negative in relay-based deployments.

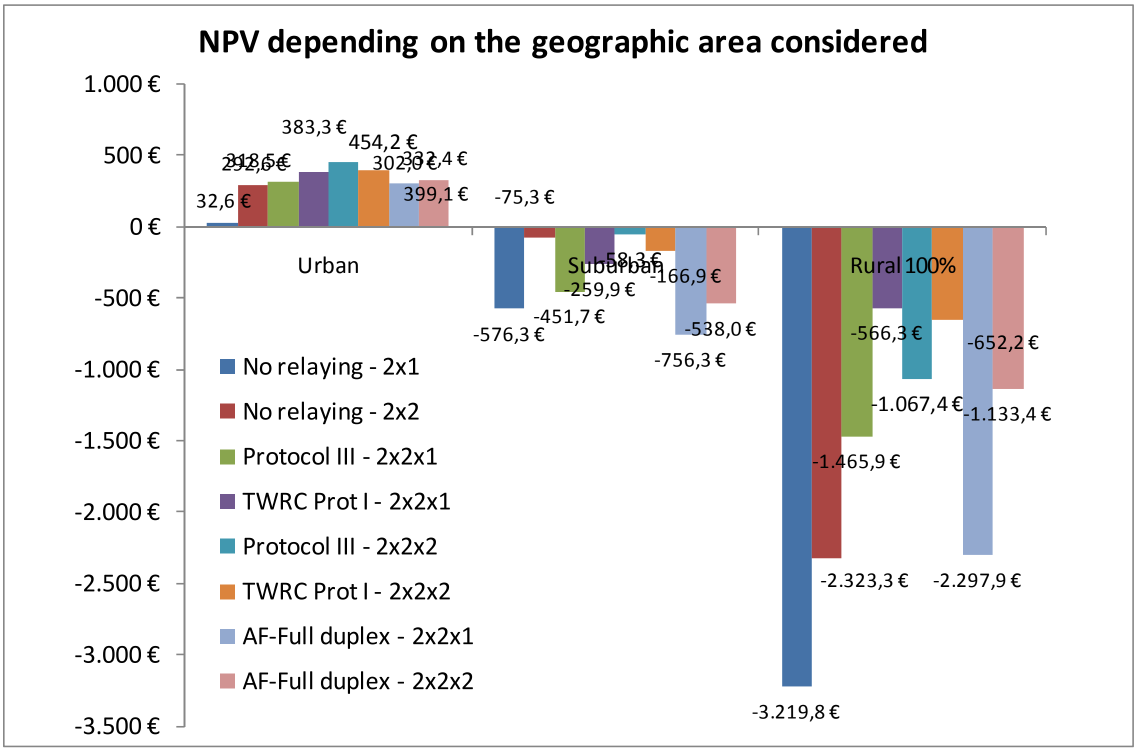

Figure 44. Net present value for different geotypes. Relaying and non-relaying networks and antenna configurations have been considered, assuming 15 MHz bandwidth

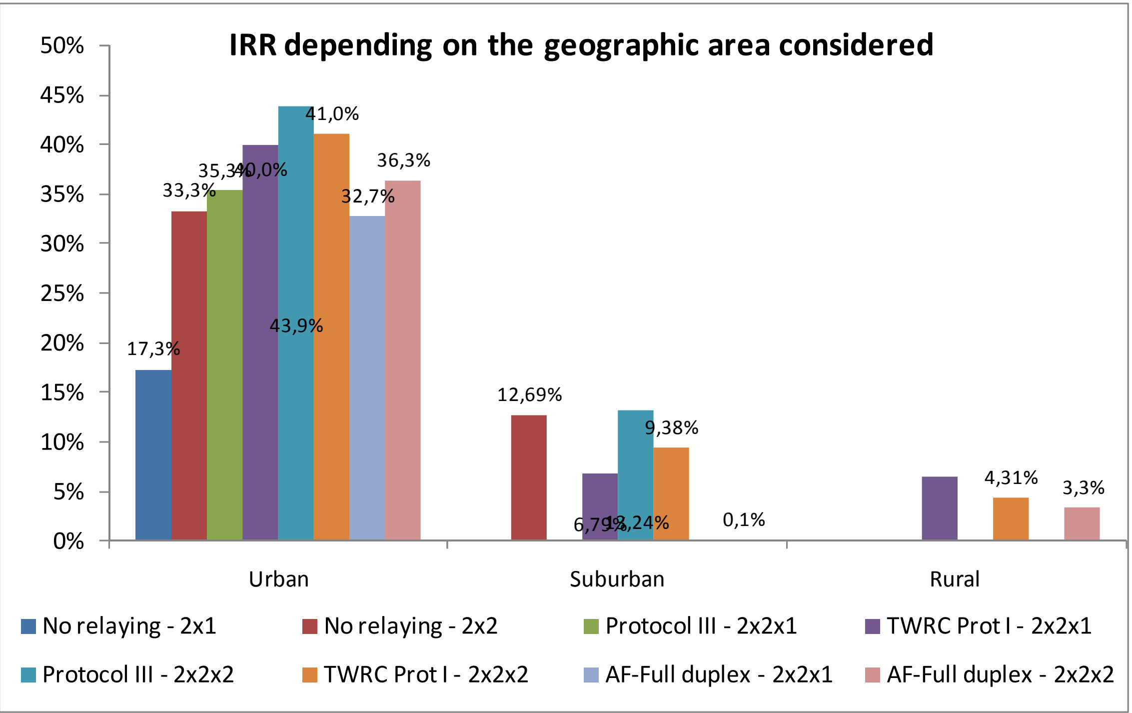

Figure 45. Internal rate of return for different geotypes. Relaying and non-relaying networks and antenna configurations have been considered, assuming 15 MHz bandwidth

7 RECOMMENDATIONS FOR AN EXPLOTATION STRATEGY

As a commercial strategy companies position themselves by leveraging its strengths. ROCKET proposals allow operators to enhance the profits of their companies and customer satisfaction.

- A ROCKET-based access network in the 2.6GHz frequency band could be used by a new entrant in the highly competitive European mobile communication market. The minimum spectrum assignment to make that roll-out profitable is 45MHz (15MHz/sector) as presented in Figure 21. As a consequence, in the case of using the channelizing proposed by CE, all the 50MHz for TDD technology should be assigned to one operator in order to guarantee the profitability of its business case.

- The profitability of this network solution is especially high in the urban areas and, to a lesser extent, in the suburban ones. Among the operator candidates to be interested in this roll-out two can be mentioned: cable operators or alternative operators that provide broadband services based in the access to incumbent networks. This roll-out could let them give respond to the fixed-mobile convergence trend and increase the infrastructure-based competition in the communication market. In fact, some examples of this trend can be mentioned as the consortium made up of bigger cable operators in the USA or the interest in the 2.6GHz frequency band shown by cable operators in the public consultation open in Spain.

- The possibility to share sites with other technologies (such as GSM, UMTS, HSPA, etc.) reduces the network roll-out costs helping to make the business model of this new entrant profitable. The adoption of a regulatory measure to facility or make compulsory this co-ubication is considered an interesting way of reducing the entrant cost of new operators encouraging the infrastructure-based competition.

- The low profitability associated with the roll-out of this technology using the 2.6GHz frequency band confirm the idea that the provision of mobile broadband services in rural areas has to be based in lower frequency bands, such as 900MHz after the refarming of this band is concluded and the 800MHz frequency band resulting from digital dividend.

Besides the above general considerations, some conclusions can be drawn based on the results obtained from the two business models analyzed:

7.1 *Use of aggregate spectrum*

First of all, it must be remembered that the assumptions made consider the possible spectrum transactions between operators that already own some spectrum and that are classified as incumbent, medium, and new entrant operators.

- According to the results obtained by applying the simple model proposed, the largest number of potential transactions in the secondary market involves a new entrant as a seller/lessee and an incumbent operator as a buyer/lessor.

- In general, the largest beneficiary of radio spectrum in the secondary market is the incumbent operator. The larger number of customers to serve makes it necessary a larger number of base stations. As a result, the cost saving associated with the access to a larger amount of spectrum per sector (allowing less base stations as a consequence of the larger cell range per base station) are the highest and make these operators the major applicants of additional radio spectrum

- Similarly, the new entrant is a leading candidate to give up spectrum. The smaller number of customers to attend implies a smaller number of base stations in comparison with the network of the rest of operators. Leasing spectrum would be probably preferred to selling, thus, keeping the new entrant its options to further deploy the network

- The spectrum available and the zone of the deployment make also a difference with regard to the most possible transactions. In urban and suburban areas, the largest cost savings occur when the operator with access to less spectrum buys/leases spectrum. In rural areas, cost saving associated with growing from 15MHz/sector to 20MHz/sector are very low due to the lower traffic level compared with that of urban or suburban areas, making these transactions less probable

7.2 Relay-based deployment

A summary of the conclusions drawn in section 6.8 follows:

- Relay networks procure a positive free cash flow one year before than non-relay networks. Furthermore, free cash flow in the first years is less negative in the case of relay-networks. This is an important result, especially for new entrants.

- EBITDA for relay networks turns positive one year before than for non-relay networks, the difference between the two of them increasing with time.

- The higher number of antennas in the terminal reduces the number of both BS and RS needed, therefore improving economic results.

- As seen in the sensitivity analysis of section 6.6.5, site co-ubication has a big impact in deployment costs. Since RS may be easily co-ubicated than BS, relay networks may therefore save more on site costs, helping to achieve better economic results.

- Among relay networks, Protocol III seems to obtain the best results from the economic point of view, due to a lower number of BS and RS required, closely followed by the TWRC. However, the difference in radiated power and its corresponding costs has not been taken into account in the analysis carried out. The use of this protocol implies the use of an advanced terminal as well as the adoption of modifications in the MAC layer, which are currently being considered in 802.16m.

- Finally, as seen in section 6.8.3, a more complete analysis should consider as well the environmental impact of radiated power. The results seem to indicate that relay networks are again more advantageous than non-relay networks in this sense.