Quality of Service and MObility driven cognitive radio Systems

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QoSMOS

D1.6

Economic benefits of a QoSMOS system

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Abstract:

This report presents a set of business case studies that were performed to investigate some of the promising applications of the QoSMOS system. The targeted business cases represent a set of very different types of applications where the technology would be used by different types of actors, which reflects the general applicability of the QoSMOS system.

The main goal of the study is to evaluate the business viability of novel concepts by identifying which type of scenarios the technology has the highest potential and what the main obstacles and challenges are. In particular, sensitivity analyses make it possible to identify which technical parameters are most important to focus future research and development work on.

Keyword list:

Business case, Cognitive Radio, Scenarios, Techno-economics

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Abbreviations

3GPP	3rd Generation Partnership Project
AL	Adaptation Layer
APPL	User APPLication
ARNS	Aeronautical Radionavigation Service
ATSC	Advanced Television System Committee
BDUK	Broadband Delivery UK
BS	Broadcasting Service
CAPEX	Capital Expenditures
CEPT	The European Conference of Postal and Telecommunications Administrations (Conférence Européenne des Administrations des Post et des Telecommunications)
CM-RM	Cognitive Manager for Resource Management
CM-SM	Cognitive Manager for Spectrum Management
CR	Cognitive Radio
DD	Digital Dividend
DFS	Dynamic Frequency Selection
DME	Distance Measuring Equipment
DoS	Denial of Service
DSA	Dynamic Spectrum Access
DTT	Digital Terrestrial Television
EIRP	Effective Isotropic Radiated Power
ECC	Electronic Communications Committee
EPC	Evolved Packet Core
FCC	Federal Communications Commission
HSPA	High Speed Packet Access
IEEE	The Institute of Electrical and Electronics Engineers
LTE	Long Term Evolution
MVNO	Mobile Virtual Network Operator
NPV	Net Present Value
NTSC	National Television System Committee
NW COORD	Network Coordination
OFDM	Orthogonal Frequency Division Multiplex

OPEX	OPerational EXpenditures
PF	Common Portfolio Repository
PMSE	Program Making and Special Event
PSD	Power Spectral Density
QoS	Quality of Service
RAS	Radio Astronomy Service
RAT	Radio Access Technology
RRM	Radio Resource Management
REG	Global & local REGulations, policy databases
SNR	Signal-to-Noise Ratio
SS	Spectrum Sensing
T2T	Terminal-to-Terminal
TCO	Total Cost of Ownership
TPC	Transmit Power Control
TRX	Transceiver
TVWS	TV White Space
UHF	Ultra-High Frequency, band designation for 300 – 3000 MHz
UMTS	Universal Mobile Telecommunications System
UWB	Ultra Wide Band
Wi-Fi	Trademark for the Wi-Fi Alliance
WiMAX	Worldwide interoperability for Microwave Access

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1 Executive Summary

This report presents a set of business case studies that were performed to investigate some of the promising applications of the QoSMOS system. The targeted business case scenarios represents a set of very different types of applications where the technology would be used by different types of actors, which reflects the general applicability of the QoSMOS system.

Since QoSMOS system solutions have yet to be deployed, it is difficult to achieve very accurate estimates for the profitability of QoSMOS-based business cases. However, it is very useful to consider the business viability of novel concepts to identify in which type of scenarios the technology has the highest potential and what the main obstacles and challenges are. In particular, sensitivity analyses make it possible to identify which technical parameters are most important to focus future research and development work on.

The “Offloading of LTE networks” business case

The “Offloading of LTE networks” business case considers a mobile operator that has been operating an LTE network in a European city for some years, but has reached a point where there start to be capacity problems. In this business case, two of the operator’s options for increasing the network capacity are compared. The first option is to use a QoSMOS system operating TV White Spaces (TVWS), i.e. spectrum in the frequency range 470-790 MHz, in a cognitive way to increase the capacity of its LTE based mobile broadband network. The second option is to acquire spectrum via a spectrum auction of “Digital Dividend 2 (DD2)” spectrum (assumed 698-790 MHz). The cost of this latter option is also believed to be similar to the cost of densifying the network, which will also be an option for the operator. It should be noted that this is not a full business case study, but rather a cost comparison between the two options. Hence, costs and revenues that are common for the two options are not taken into consideration.

The business case is calculated for a hypothetical western European city with 1 million inhabitants covering an area of 200 km^2. The city has a downtown area which covers 50 km^2 with 0.5 million inhabitants and an urban/suburban area which covers 150 km^2 also with 0.5 million inhabitants. The study period is from 2015 to 2020. The starting year has been chosen based on when it is expected that the concept is sufficiently mature both with respect to technology and business aspects.

It is assumed that the mobile operator has an existing infrastructure in the city, and that no additional base station sites are needed in the two options considered.

The cost comparison between the QoSMOS based and DD2 spectrum based options gave a difference between the Net Present Values (NPVs) of 3.0 million € in favour of the QoSMOS based option. Since the technology for the QoSMOS based option is not yet developed, many of the assumptions are very uncertain. In addition the cost of the Digital Dividend 2 spectrum, which is the dominating cost of the DD2 business case, is very market and time dependent. Hence, it is not possible to conclude that using cognitive LTE is a more cost efficient solution for capacity enhancements than buying more spectrum in a DD2 auction, but the results indicate that using a QoSMOS based approach can be a competitive solution.

The sensitivity analysis showed that the most important parameter to estimate accurately when deciding which of the two options to choose is the price of the Digital Dividend 2 spectrum. This parameter totally dominates the business case for the DD2 option. The cost difference between a cognitive LTE terminal and a conventional LTE terminal that supports operation in DD2 spectrum is also a parameter that is important to estimate with good accuracy. An interesting observation is that the spectrum database fee turns out to have little impact on the profitability of the QoSMOS based option.

The “Rural Broadband” business case

This business case considers the UK as an example for deploying rural broadband. One of the objetives of the UK governement’s Broadband Delivery UK (BDUK) programme is to deliver broadband with at least 2Mb/s to virtually all UK communities by May 2015 [BDUK2011]. To achieve this broadband must be provided for not-spots. In this work, not-spots are defined as premises that cannot get at least 2Mb/s download speeds at peak-hours. This business case looks at the scenario where a fixed-line operator provides a broadband service to rural not-spots using TVWS. The homes will have roof-top antennas pointing towards the base station.

The business case is calculated for an Internet service provider to offer a broadband service to rural not-spots using the services of a fixed line network operator.

It is assumed that the required coverage can be achieved solely by reusing the fixed line network operator’s existing sites, i.e. no new sites would be needed. These sites are already equipped with the necessary backhaul and power supply capabilities for the rural broadband solution.

The business case is calculated for the UK with a nominal 1 million rural not-spots. The study period is from 2013 to 2023. The starting year has been chosen based on (a) meeting the targets of the Digital Britain program and Ofcom and (b) when TVWS is expected to become available in the UK, and does not assume the availability of the new QoSMOS TRX equipment.

The business case calculations show that the TVWS rural broadband solution requires a large capital investment and have tight margins. Over ten years, the calculated NPV is 115 million €. Cash flow decreases over the first three years as a result of the phased deployment and gradual uptake of customers in served areas. From year 3, the cash flow starts to increase, becoming positive early in the eighth year.

The sensitivity analysis shows that the TVWS solution business case is highly sensitive to (a) the revenue that can be charged per customer and (b) the number of customers that subscribes to this service. This risk can be expected as this business case looks to provide a service in not-spots; areas where, up until now, it has not been economically viable to provide an adequate broadband service. For such areas, the TVWS may be the best or cheapest technical option. As such, any network operators with a legal obligation for such coverage might still be attracted to the solution even if the NPV were negative. Also, further incentives could be provided by local or national government programmes who wish to encourage increased broadband coverage to underserved areas.

The “Cognitive Femtocell” business case

In this scenario a fixed network operator uses cognitive femtocells to offer a mobile service to its subscribers. The operator uses TV White Spaces (i.e. vacant spectrum in the frequency range 470-790 MHz) in a cognitive way to extend its business to include also mobile broadband services. By cognitive operation the range of the femtocells is increased to cover also outdoors areas nearby the home or office where it is located. The fixed operator has the advantage that it already provides fixed broadband to a large number of customers, which can be used as backhaul for the customers’ femtocells.

The main advantage of this solution for the fixed operator is that it can extend its business towards mobile services without acquiring spectrum licences. It can utilize its own infrastructure and the existing customer relations.

Because the cognitive femtocells cannot, especially in the start phase, provide good coverage all over the targeted area, it will be necessary that the operator has a roaming or MVNO (Mobile Virtual Network Operator) agreement with one (or more) of the existing mobile operators.

The business case is calculated for a hypothetical western European city with 1 million inhabitants covering an area of 200 km^2. The city has a downtown area which covers 50 km^2 with 0.5 million inhabitants and an urban/suburban area which covers 150 km^2 also with 0.5 million inhabitants.

The study period is from 2015 to 2020. The starting year has been chosen based on when it is expected that the concept is sufficiently mature both with respect to technology and business aspects.

Customers signing up for the mobile service will be given a cognitive femtocell which they mount in their home or office. When the customers use their mobile devices at home/office they will connect to the cognitive femtocell. From experience it is known that a large part of the traffic from a subscriber is generated while the subscriber is at home or in his or her office, and this traffic will then go in the fixed operator's own network. In addition, customers can also use other customers' femtocells when they are within coverage of one or more of these. Hence, the fixed operator will gradually get more of the income from its customers' mobile traffic.

The results from the business case study show that this is a promising business case. The investments the first years are moderate since the fixed infrastructure is already there and the main initial investments that the fixed operator must do are for the mobile core components. The general OPEX will be high the first years, mainly due to high marketing expenses. Together this gives a moderate negative cash flow the first years. The accumulated cash flow is estimated to get positive after about 4 years. The NPV for the 5 year study period (2015 – 2020) is 4.5 million €.

But even if this business case is promising it should be realised that many of the assumptions are very uncertain and hence that no firm conclusions can be drawn. The results should be interpreted as only indicating that this is a possible business case.

The sensitivity analysis shows that the ARPU (subscriber fee) and the general OPEX were the most critical assumptions in the business case analysis. The cost of a cognitive femtocell is not among the most critical parameters, but still has notable influence on the business case profitability. Research and development work should focus on reducing its cost.

The average cognitive femtocell installation costs can also influence the business case profitability. Hence it is important that the Plug'n'Play functionality works properly so that assistance from a service engineer is only exceptionally needed.

The cognitive femtocell coverage range is of some importance in suburban areas, but of less importance in downtown areas where the density of femtocells will be high. It is important to determine what the coverage range will be in the area where a cognitive femtocell deployment is considered. It is also important to give the subscribers instructions on where to put the cognitive femtocell in order to get a good outdoor coverage.

The difference in the cost between a traditional LTE terminal and a cognitive LTE terminal is not expected to be a critical parameter. Also the spectrum database fee and the cost of the mobile core components have little effect on the business case profitability.

The "Machine-to-machine" business case

This business case takes the point of view of an operator deploying the infrastructure for a machine-to-machine (M2M) network in the UK. This could be an existing network operator or a new entrant. As ubiquitous coverage is targeted to enable the growth of many of the potential M2M applications, TVWS are seen as a suitable frequency band due to the low cost and good propagation characteristics.

As this business case requires a large capital investment and has tight margins, the NPV is considered over 10 years. Over shorter periods a poor NPV will be almost certain due to the high initial investment and tight margins. Over ten years, this produces a NPV of 16.4 million €. Cash flow decreases over the first few years. This is a result of the CAPEX from the phased deployment added to the fact that uptake would gradually increase only once an area has coverage. From year 4, the cash flow starts to increase, becoming positive early in the ninth year.

The business case model shows that an operator, after a large capital investment, would be able to make a profit within ten years. With the base values assumed here the NPV over ten years is 16.4 million €.

This business case has made assumptions about the scale of the M2M market that an operator could service. There is much uncertainty about the base value assumed of 50 million connected devices. The sensitivity analysis shows that this uncertainty can improve the NPV by hundreds of millions of € or make the NPV negative by hundreds of millions of €. The sensitivity analysis also reveals a similar level of change with the uncertainty in how much revenue can be generated per connected device.

The results clearly show the potential for an Operator to make a successful business. However, the risk is quite high if the number of connected devices or the revenue per connected device is overestimated.

The business cases in perspective

The base case NPVs for the different business case scenarios vary from +3 to +115 million €, which does not reflect how relatively good the business cases are but rather the scale of the deployment considered. Since all the NPVs are positive when their base case assumptions are used, it can be concluded that all the considered business cases are potentially economic viable.

The subscription fee and number of subscribers (or equivalently the revenue per connected device and number of M2M devices in the cognitive ad hoc network case) are two of the most critical parameters in all business cases except the LTE offloading case. Hence it is very important to thoroughly investigate these parameters for the market in question before any investments are made. These parameters depend to a large degree on factors that are not related to the QoSMOS solution, but rather to external factors like the competition from other actors and the general economic climate. However, it also depends on the performance and quality of the service that can be provided by using the QoSMOS solution. Hence, it is important to focus on the QoSMOS system performance in future research and development work in order to ensure that it is possible to provide services that are at least as good and preferably better than what the customers can get using competing solutions.

Since the LTE offloading business case only compares costs between two alternative solutions (using TV white spaces or buying DD2 spectrum), the subscription fee and number of subscribers are not input parameters. In this case it is the price of the DD2 spectrum that is the most critical parameter. However, this parameter is unrelated to the QoSMOS solution.

Regarding the most important QoSMOS related parameters, there is some variation between the business cases. The cost of the cognitive terminal is important in the LTE offloading case and the rural broadband case, but not in the cognitive femtocell case. The cost related to the cognitive base station is important in the LTE offloading case and the cognitive femtocell case. Installation costs are important in the rural broadband and the cognitive femtocell cases.

The risk or uncertainty also varies between the business cases. The LTE offloading and cognitive femtocell cases have moderate risk while the rural broadband and M2M cases have high risk. This is also reflected in the study periods where the business cases with moderate risk have positive NPVs for a study period of 5 years while the high risk business cases give positive NPVs for a study period of 10 years.

It should also be noted that in all business cases the spectrum database fee turned out to be a less critical parameter. Hence, this expense is not expected to affect the attractiveness of QoSMOS solutions, and their uptake in the market, significantly.

2 Introduction

This report presents a set of business case studies that were performed to investigate some of the promising applications of the QoSMOS system. The targeted business cases were chosen from a wide range of potential applications, where the selection was done based on a set of criteria. This resulted in a set of very different types of applications where the technology is used by different types of actors, which reflects the general applicability of the QoSMOS system.

The business case studies were done in close cooperation with the technical work in the project. A “support group” for the business case study was formed consisting of key persons from different work packages and different partners. This “support group” was regularly consulted to ensure that the assumptions used were in accordance with results obtained in other work packages and to get feedback on the work done. In addition, the discussions with the “support group” ensured that both the detailed description of the business cases and the assumptions were properly anchored in the project.

It was realized from the start of the project that it would be difficult to achieve very accurate estimates for the profitability of QoSMOS based business cases since QoSMOS systems have yet to be deployed. In spite of this, we believe that it is very useful to consider the business viability of novel concepts to identify in which type of scenarios the technology has the highest potential and what the main obstacles and challenges are. In particular, we believe that sensitivity analyses make it possible to identify which technical parameters that it is most important to focus future research and development work on.

The business case analysis work and the technical development work has mutually influenced each other during the project. Results from the technical work have influenced the assumptions made in the business case analysis and the business case analysis has pointed out which components of the QoSMOS architecture are most important to improve.

The QoSMOS system can be applied to any frequency band, however in order to quantify the potential of deploying QoSMOS system solutions both technical and economic constraints must be determined. In all business cases it is assumed that the QoSMOS system operates in TV white space spectrum. The reason for this is that it is the only frequency band for which operational constraints, like the maximum allowed transmission power are given or indicated by regulators (FCC and Ofcom), and TVWS is a suitable spectrum band to use due to its favourable propagation properties as well as the fact that it is currently being opened up for opportunistic access.

The availability of frequencies in the TVWS spectrum is more “static” than in most other frequency bands. Therefore cognitive use based on geo-location and a spectrum database is the most adequate solution. It will be assumed that no spectrum sensing is required. Users with higher priority (TV transmitters and wireless microphones) must update the spectrum database to avoid secondary usage of their spectrum.

In all business cases it is also assumed that the spectrum databases are operated by a third party and that the QoSMOS operator must pay a fee.

2.1 Overview of the QoSMOS system

The QoSMOS system is defined by an overall architecture with options containing the necessary functional entities to support opportunistic and shared spectrum access while ensuring managed QoS and mobility. The QoSMOS system maps to known standard architectures as e.g. the 3GPP EPC and Wi-Fi/Internet. This is all well documented in other QoSMOS reports [D2.2][D2.3]. The essence of the architecture has been refined into the QoSMOS reference model which is shown in Figure 1. The QoSMOS reference model identifies the functional entities as well as their interactions.

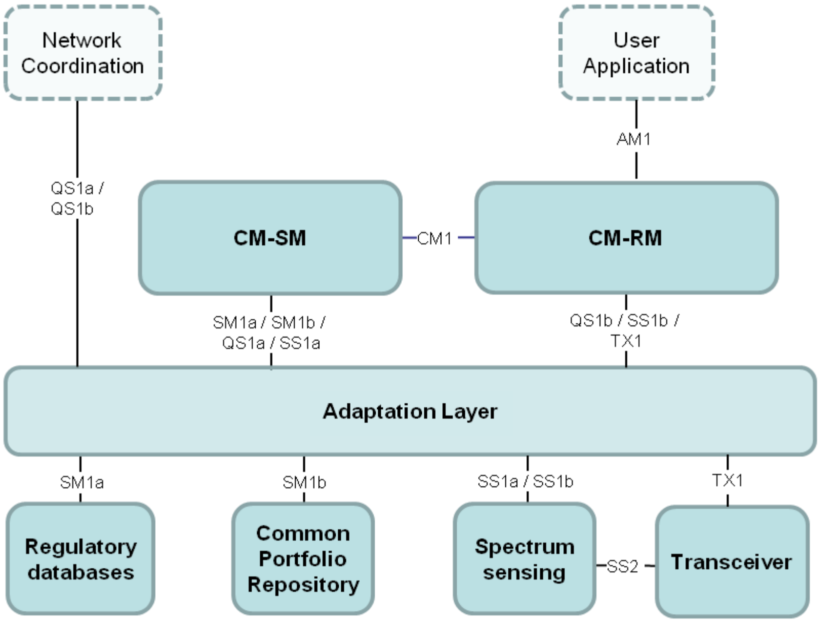

Figure 1 QoSMOS reference model (from D2.3)

The role and responsibilities of the QoSMOS functional entities are described in Table 1. Additional details, such as the interfaces definitions, can be found in [D2.2].

Table 1: Description of QoSMOS functional entities

Functional blocks	Description
Spectrum sensing (SS)	The SS is responsible for controlling the sensing process by interacting with the sensor, for making decision (about the presence or absence of an incumbent for example) based in sensing measurements, and to report the sensing measurements back to the requesting CM management entities.
Cognitive manager for spectrum management (CM-SM)	The CM-SM is responsible for building the spectrum portfolio based on the external constraints (regulatory policies, operator policies…) and on spectrum sensing results. This spectrum portfolio contains spectrum usage policies and spectrum usage information, putting constraints on the decisions which can be taken by the other cognitive entities of the QoSMOS system.
Cognitive manager for resource management (CM-RM)	The CM-RM is responsible for providing service to the application layer according to an agreed level of quality of service (QoS). This includes being responsible for the allocation of the spectrum following the policies contained in the spectrum portfolio, managing the mobility of the users and protecting the incumbent users.
Transceiver (TRX)	The TRX is able to perform synchronized data transmission and to provide unidirectional or bidirectional dedicated broadcast and multicast channels on different spectrum band operated by the supported heterogeneous radio access technologies. Additionally, it provides CM-RM with measurement reports and transceiver capabilities (i.e. capabilities to transmit and receive data).
Common portfolio repository (PF)	The PF is used to store the spectrum portfolio and to exchange context information among network entities. The information includes available frequency bands and spectrum usage policies….

Functional blocks	Description
Global & local regulations, policy databases (REG)	The REG is used to provide regulatory information for spectrum assignment (licensee status, usage requirements).
User application (APPL)	The APPL represents any application running on a user terminal providing a service to an end-user, and requiring access to the network. The user application should be able to express its requirements in terms of QoS for the CM-RMs to decide on admitting or refusing the associated service.
Network coordination (NW COORD)	The NW COORD has the overall responsibility of the configuration of an operator's infrastructure network. It includes part of the mobility management, and monitors the overall performance of the networks under its control to eventually decide on the reconfiguration of network segments.
Adaptation Layer (AL)	The AL provides a seamless and RAT-agnostic communication between some of the different functional entities. This mainly applies to the communication in heterogeneous configurations to facilitate the data exchange between different network elements.

2.2 Selection of business cases

The QoSMOS project initially selected and defined 6 distinct scenarios as documented in D1.2 and shown in Figure 2 .

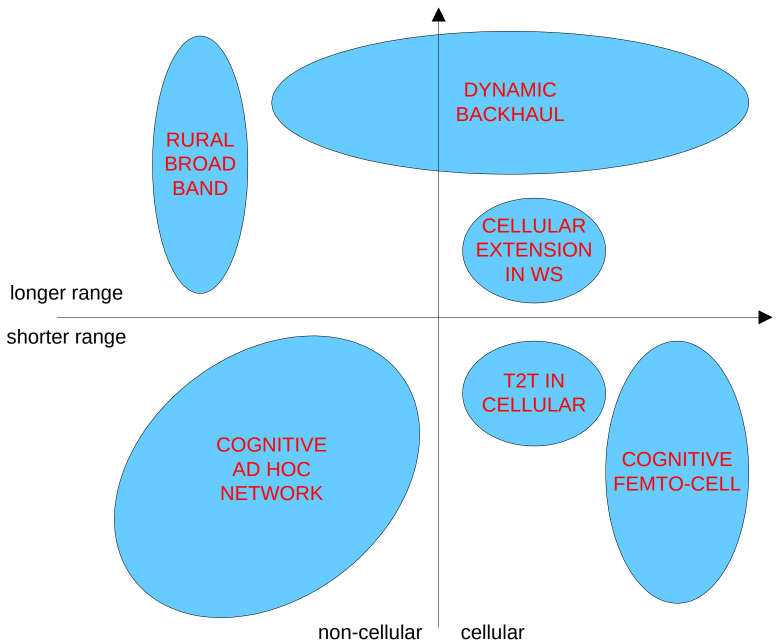

Figure 2 The original six QoSMOS consolidated scenarios grouped by range and network architecture

A number of commercial evaluation criteria were defined and used to single out the four most promising cases from a business point of view.

2.2.1 Evaluation criteria

The criteria shown below were used for selecting the most interesting and promising scenarios for business case studies. Each D1.2 scenario was evaluated by all partners in QoSMOS according to each criterion by three grades: Positive (+), Neutral (0), Negative (-). It was also possible to answer “No opinion” on some points. It was also possible to provide comments to explain and/or clarify the grading.

- Market Potential

  The scenario should have a large market potential, e.g. with respect to the number of user terminals or expected revenue for the service. It is a fundamental goal for QoSMOS to develop a system with high market potential and hence be important for European industry.

- Best Solution

  No other solution should appear as a better (w.r.t. e.g. performance, lower cost, have environmental benefits, etc.) solution than QoSMOS for the given scenario. It is important to exclude possible usage scenarios for cognitive radio that seems to have a large potential but which can be better solved by other technologies

- Technical Feasibility

  It must be probable that this system can be implemented with current state of the art technology or beyond state of the art technology achievable in the scope of the project.

- Economic Feasibility

  It must be probable that within a period of 3-10 years it will be possible to produce equipment and services to a cost that match the users’ willingness to pay for the equipment and services. In addition the scenario must offer profitability for all major actors in its ecosystem.

- Regulatory Feasibility

  If the solution requires regulatory changes in order to be deployed, the changes should be such that it is reasonable to expect that they can be realized within a reasonable time frame.

- Ecosystem Feasibility

  How much is the QoSMOS scenario dependent on a larger ecosystem? This system may consist of customers, partners, suppliers, competitors and local and national authorities. If the scenario imposes great changes in the ecosystem (e.g. roles that disappear), it will be much harder to get acceptance for the solution in the industry. The affected players may work against acceptance of e.g. regulatory and standard changes that are necessary for the realization of this scenario. Also, it must be probable that all of the necessary actors will be able to take part in the ecosystem required to realize the QoSMOS solution.

- Benefits for the society

  Local or national authorities may be willing to support deployment of a system if the social benefits it represents are large. Political support can also make it much easier to get acceptance for regulatory changes.

2.2.2 Outcome of evaluation

The table below shows the outcome of the evaluation with two options for weighting between the criteria. Weight 1 rates all criteria equally important, while weight 2 emphasizes the market potential as well as being the best solution.

Table 2 Commercial evaluation of QoSMOS scenarios

Criterion	Dynamic backhaul	Cellular extension in the WS	Rural broadband	Cognitive ad hoc network	Direct terminal-to-terminal in cellular	Cognitive femtocell	Weights 1	Weights 2
Market potential	0.18	0.82	0.82	0.45	-0.10	0.91	1	5
Best solution	0.11	0.60	0.30	0.40	-0.30	0.70	1	5
Technical feasibility	0.60	0.90	0.91	0.55	0.45	0.64	1	3
Economic feasibility	0.50	0.60	0.45	0.40	0.18	1.00	1	3
Regulatory feasibility	0.78	0.45	0.90	0.60	0.40	0.91	1	3
Ecosystem feasibility	0.78	0.78	0.78	0.63	0.50	0.67	1	1
Benefits for the society	0.64	0.82	1.00	0.82	0.36	0.73	1	1
Total score with weights 1	**0.51**	**0.71**	**0.74**	**0.55**	**0.21**	**0.79**		
Rank, weights 1	**5**	**3**	**2**	**4**	**6**	**1**		
Total score with weights 2	**0.41**	**0.69**	**0.67**	**0.49**	**0.09**	**0.81**		
Rank, weights 2	**5**	**2**	**3**	**4**	**6**	**1**		

Both weightings give similar results with Cognitive femtocell on top except that Rural broadband and Cellular extension in WS changes order as number 2 and 3.

2.2.3 Final scenarios for business case evaluation

The scenario with the highest score is “Cognitive femtocell”. Following up are the “Cellular extension in whitespace” and “Rural broadband” with almost similar scores. These three scenarios are the ones chosen for the business case studies. Since there are many similarities between the latter two, both from a business and technical point of view, we regard these as subcases of a common “Cellular extension in whitespace” scenario. The scenario ranked fourth is the “cognitive ad hoc network”. A machine-to-machine (M2M) implementation of this scenario is an example which is currently receiving a lot of attention. Therefore the analysis of the cognitive ad hoc network has been done less rigorously (because of its fourth ranking), and specifically for the M2M case, since this has a great momentum in the market for future TVWS systems. The list is then as follows:

- Cellular extension in whitespace
  - Subcase 1: Offloading of LTE networks
  - Subcase 2: Rural broadband
- Cognitive femtocell using whitespace
- Machine-to-machine (M2M) in whitespace (as example of a cognitive ad hoc network)

A further description follows in the next sections.

2.2.3.1 Offloading of LTE networks

This is a scenario where mobile networks (e.g. LTE) will utilise whitespace (WS) spectrum in addition to their own licensed spectrum as shown in Figure 3 . This additional spectrum allows for mobile operators to gain additional bandwidths to benefit the user.

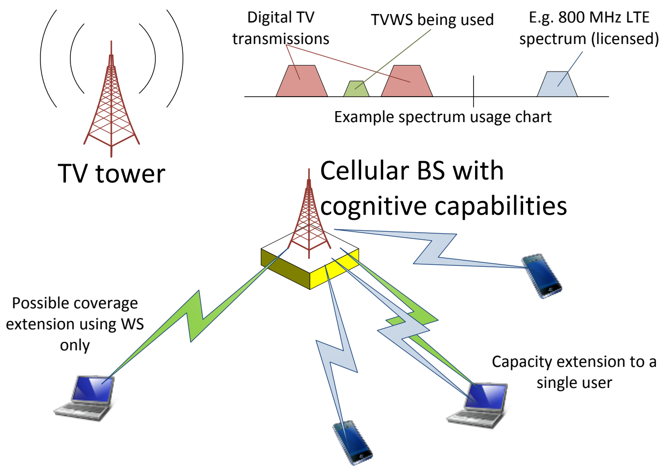

Figure 3 Overview of Cellular extension in whitespaces – offloading of LTE networks

A mobile operator normally operates the cellular system using its own licensed bands, thus avoiding any conflict with other co-located services like e.g. a TV broadcast system operating in another frequency band. In this scenario, a TV broadcast system can be the incumbent (primary) system and the cellular system is the opportunistic (secondary system). The cellular network base stations may then opportunistically utilise vacant spectrum (location and time dependent) in the incumbent's band for expanding their operational bands in addition to their licensed band without causing harmful interference to the incumbent system. In the case of multiple operators, such opportunistically utilised spectrum is shared among them. The sharing mechanisms and management are done by a spectrum manager using a spectrum database. The additional QoSMOS defined spectrum management and medium access functions, needed together with the extended physical layer is integrated into one single network architecture as defined in QoSMOS deliverable D2.3

The opportunistic use of spectrum could be used to enhance the coverage or capacity for a mobile operator. These represent long range and short range requirements respectively. The suitability of a spectrum band for this scenario therefore depends on whether it is to be used for coverage enhancement or capacity enhancement. The features of this scenario are beneficial for the operators to obtain increased operational bandwidths, resulting load balancing, improved link quality, more flexible services, etc.

2.2.3.2 Rural broadband

This involves the provision of wireless Internet connectivity to homes in rural locations through a base station as depicted in Figure 4. This scenario has high QoS requirements, to accommodate the range of Internet usage that domestic customers require, but has a very low mobility requirement (as the locations of homes are fixed). For this system to be deployable in all rural areas it should have frequency flexibility, which is why a QoSMOS solution can be successful.

The homes are likely to have antennas on the outside of the home. By having the antennas on the outside of homes propagation loss is reduced resulting in potential benefits such as lower power consumption, greater range and the ability to use cheaper (less sensitive) equipment. This scenario is expected to use low frequency spectrum bands that are available for opportunistic access. The low frequency of the band is desirable due to the improved propagation characteristics.

The stakeholders in this scenario are mainly the network operator and the service provider. This scenario could be the most economically viable way to provide Internet access to rural locations that currently either don't have a fixed line broadband connection, or only have a low data rate broadband connection. The link length is expected to be between 1 and 10km. There is no actual limit on the minimum distance. The limit on maximum distance is dependent on the transmit powers allowed, the frequency being used and the terrain.

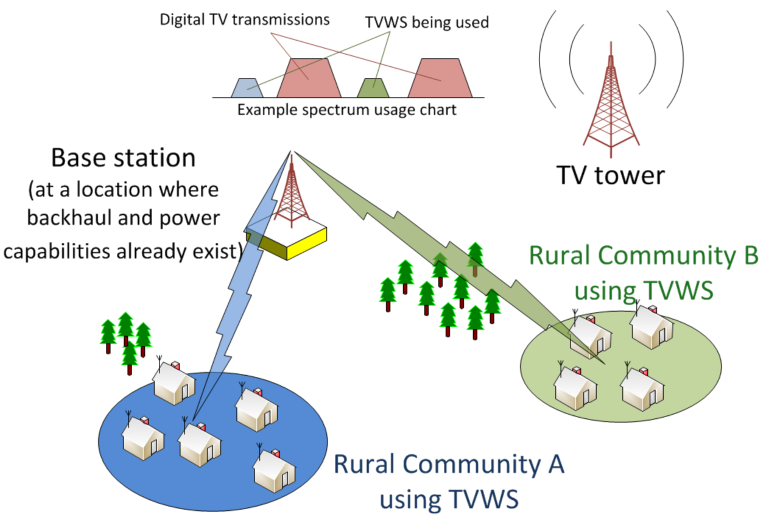

Figure 4 Overview of Rural broadband

A typical example of how rural broadband connectivity might be implemented is to use TVWS spectrum to connect an isolated village that has little or no Internet connectivity and for which it is not cost effective to deploy a fixed line solution. The main feature of a QoSMOS rural broadband solution is the use of low frequencies which means that transmit powers can be kept relatively low. This reduces power consumption (especially for uplink transmissions). While being able to function in low frequency spectrum the system must still remain dynamic so that it is not restricted from working in certain rural areas where the spectrum availability is different or changes.

2.2.3.3 Cognitive femtocell

The femtocell scenario, depicted in Figure 5, describes a user situation with low mobility, but high demands on throughput and QoS. It may also be described as a "hot spot" scenario. Femtocells are small base stations connected to a cellular core network via a fixed infrastructure and could also include managed Wi-Fi type access points connected in infrastructure mode. Femtocell hot spots are typically used as domestic wireless broadband solutions and as public hot spots in e.g. commuter areas, cafés and similar. Both indoor and outdoor deployment is possible.

The cognitive femtocell scenario will typically comprise two main node types; a base station or access point, and the user terminals. The access point, or "femtocell" node, must have gateway functionality and access control mechanisms. The full range of services will be in demand in such a scenario, from voice telephony to broadband multimedia. The number of simultaneous users per base station/access point is predicted to be low (from 1 to 10).

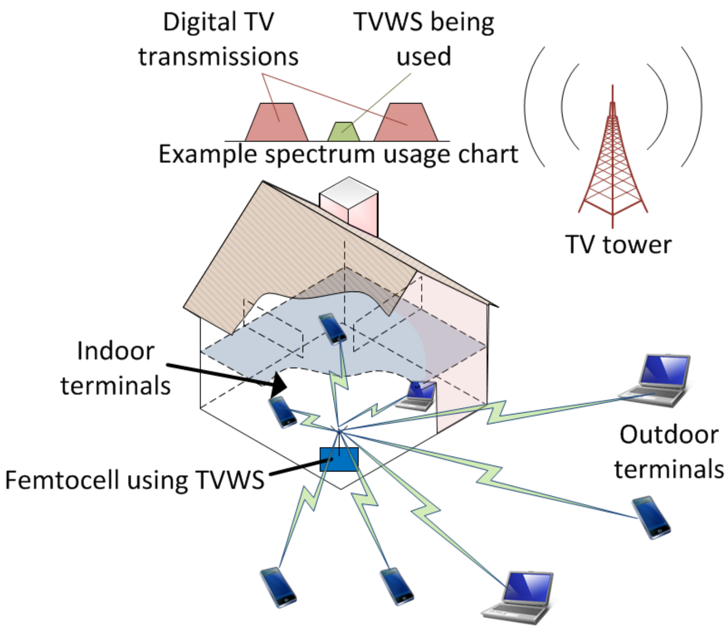

Figure 5 Overview of Cognitive femtocell

Examples of this scenario are:

- Private wireless access solution of the same type as Wi-Fi is used today. This typically comprises single femtocells with access control
- Public hot spots, where several femtocells comprise a larger coverage area. Access may be open for all users in the area or limited on commercial basis
- The use of indoor femtocells to provide outdoor coverage in e.g. urban/suburban streets. This can be similar to services and coverage based on sharing access points. This is the example chosen for the business case evaluation in Chapter 5.

The main features of using cognitive radio for femtocells are:

- Better interference control than current 3G/LTE femtocell technology which can improve capacity and coverage
- Better user experience due to more frequencies being available and potentially larger coverage

2.2.3.4 Machine-to-machine (M2M) in whitespace

Machine-to-machine (M2M) communication is expected to grow dramatically over the next few years [Ericsson2011] and could be well suited for opportunistic and shared spectrum access. M2M comprises a lot of use cases. Here we emphasize interconnection of many small devices which send and receive small amounts of data belonging to a service with relaxed real-time demands. Devices can appear and disappear, making this a form of ad hoc network, with infrastructure topology. The scenario is depicted in Figure 6.

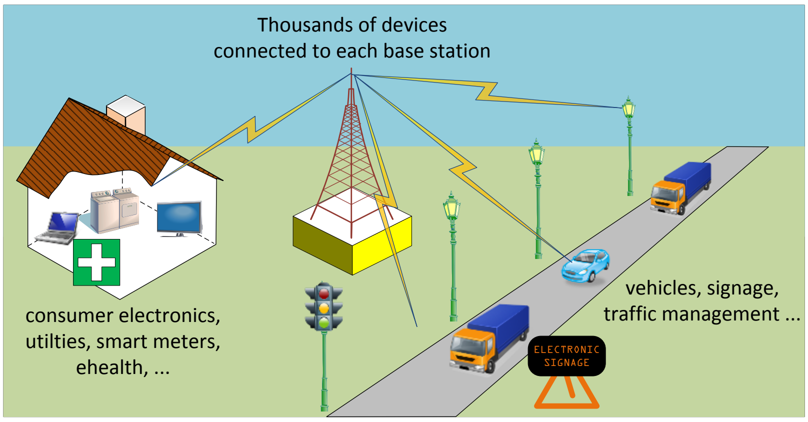

Figure 6 M2M in whitespace scenario

Possible use cases for the M2M scenario are: health care, utilities, transportation, smart devices

- Transportation. This includes Freight and luggage tags sending e.g. location info regularly to a control centre. This also includes many more use cases such as traffic management.
- Smart metering as part of the future electricity smart grid. This is one of the key examples used as a basis for the business case evaluation in chapter 6.
- Smart devices. This could include consumer electronics, white goods, etc.
- eHealth such as personal monitoring systems.

This list, far from being exhaustive, is only the tip of the iceberg in terms of which M2M scenarios could use the M2M infrastructure. More details can be found in [Ericsson2011], [Webb2012] and [Egan2012].

3 The “Offloading of LTE networks” business case

3.1 Motivation

This business case considers a mobile operator that has been operating a LTE network in a hypothetical European city for some years, but has reached a point where there start to be capacity problems. The main reason for the capacity problems are increased traffic generated by each subscriber and possibly also an increase in the number of subscribers.

Traditionally, there are two ways to increase the capacity of a mobile network. One possibility is to buy more spectrum, but this can be expensive or even impossible. The other possibility is to increase the density of the network by deploying more base stations, which is also costly and it can be difficult and time consuming to get access to locations for the new sites.

Cognitive radio makes a third option possible, where the capacity is increased by utilizing spectrum opportunistically. In this case the mobile operator gets access to new spectrum for a much lower cost. Such spectrum can be allocated to the operator in several ways. Some possibilities are:

- To rent spectrum from the spectrum license owner for a certain time period
- To get secondary access to spectrum for a certain time period by winning an auction (e.g. via micro trading)
- Share access to a free spectrum block with other cognitive radios. The spectrum block might or might not have primary licensed users that must be protected from interference.

Cognitive radio based schemes have many advantages. In the first place, they will lead to better utilization of the spectrum resources, which is important for regulators and authorities. Secondly, they reduce the upfront investment required since it is not necessary to buy an expensive spectrum license. This will make it much easier for new actors to enter the market. Finally, dynamic spectrum allocation is much more flexible than the traditional command and control regime. Operators can rent spectrum only when needed, e.g. during peak hours or special events. And the spectrum needs only to be rented in those geographical locations (hot-spots) where there is a capacity shortage.

However, the cognitive radio approach also has several drawbacks. Since opportunistic spectrum is only available as long as the associated primary systems are not using it, the availability of such spectrum is usually uncertain and the operating frequency must be changed from time to time as primary users are detected or the primary system re-claims the spectrum. Also, there are usually some restrictions on how cognitive radios can operate in a given spectrum. For example, there are often limitations on the maximum EIRP the base stations and user terminals can use.

The goal of studying this business case is to compare the novel cognitive radio based approach to increasing capacity in cellular networks to the traditional approach of increasing the capacity by buying more spectrum. The other traditional approach of densifying the LTE network will not be studied. However, experience has shown that the price to be paid in auctions for spectrum in attractive frequency bands is very high and that the final price is often a good approximation of the amount needed for increasing the capacity in other ways, including increasing the network base station density.

3.2 Business case description

The business case will be calculated for a **mobile network operator** that needs to increase its LTE capacity. The operator is assumed to be one of the three or four major mobile network operators in the studied area/country. It has an extensive infrastructure in the area consisting of base station sites with backhaul capabilities. In addition, it has an existing organisation for sales, marketing, technology and operation.

The operator will use **TV White Spaces (TVWS)**, i.e. spectrum in the frequency range 470-790 MHz), in a cognitive way to increase the capacity of its LTE based **mobile broadband** network. The cognitive radio system will be based on LTE but adapted for cognitive use in the TV white spaces and will be denoted as cognitive LTE. This case can be seen as an alternative to waiting for some of these frequencies to be freed from TV use and auctioned for mobile broadband use (the second Digital Dividend or “Digital Dividend 2 (DD2)”, 698 – 790 MHz).

The LTE offloading business case only compares costs between two alternative solutions (using TV white spaces or buying DD2 spectrum). Parameters that are common to both solutions, like the subscription fee and number of subscribers, are not considered in the calculations since it is only the cost differences that matter.

The QoS and mobility support offered by the cognitive radio system is assumed to be as good as in traditional mobile broadband based on the LTE technology. The key focus for the QoSMOS project is to develop cognitive radio solutions able to deliver quality of service (QoS) in a mobile environment over a wide range of target scenarios. QoS and mobility are the two main pillars of the QoSMOS project.

Cognitive functionalities must be implemented both to terminals and to base stations.

Physical site infrastructure (mast, towers, cabinets, antennas, power supply, etc.) is one major cost factor in the mobile business. Therefore the intention is to base this business case solely on the **reuse of existing sites** (i.e. no new sites will be needed).

The business case is calculated for a hypothetical western European city with 1 million inhabitants covering an area of 200 km^2. The city has a downtown area which covers 50 km^2 with 0.5 million inhabitants and an urban/suburban area which covers 150 km^2 also with 0.5 million inhabitants.

The study period is from 2015 to 2020. The starting year has been chosen based on when it is expected that the QoSMOS system would be sufficiently mature both with respect to technology and business aspects.

3.3 Technical considerations

3.3.1 The cognitive LTE transmission scheme

It is assumed that the cellular operator gets cognitive access to one 8 MHz TV channel, and that it uses a system based on LTE to communicate in this channel. It is assumed that the FBMC/SMT modulation scheme presented in deliverable D4.2 [D4.2] is used.

However, a small modification to the FBMC/SMT scheme in D4.2 is required in order to make the scheme fit into a LTE context where transmission opportunities are allocated as Resource Blocks (RBs). In D4.2, the number of active carriers is 482. Unfortunately, the only prime numbers that divide 482 are 2 and 241 making it difficult to divide the carriers into RBs. To get a more appropriate subdivision in RBs, the number of carriers is reduced by 2 to 480 (= $2^5 \cdot 3 \cdot 5$).

We assume that the 480 carriers are grouped into 40 RBs, each having 12 subcarriers. The frequency separation between carriers is 15 kHz, hence the total bandwidth of the signal is 480·15 kHz = 7.2 MHz and a RB is 12·15 kHz = 180 kHz wide. This is the same RB bandwidth as for conventional LTE systems.

3.3.2 The capacity of the cognitive LTE system

We will consider the case of a uniform capacity increase throughout the network, i.e. each base station is equipped with a new cognitive radio for each sector. It is assumed that the operator gets cognitive access to a bandwidth corresponding to one 8 MHz TV channel. In the simplest case the operator can use the same TV channel throughout the city. However, the spectrum situation might be more complex such that the operator has to use different TV channels in different parts of the city.

When calculating the capacity that can be achieved by having access to 8 MHz of spectrum in the TVWS, it will be assumed that the same TV channel is used throughout the city. This will give the most conservative results since all sectors then will interfere with each other. A frequency re-use of 1 will be assumed, meaning that all sectors on all BSs use the same frequencies. This is the way most LTE systems are operated.

There will be limitations on the maximum EIRP values for the base stations and user terminals. Currently, there are rules specified by FCC in the US and statements from OFCOM in the UK giving limits that can be used in the calculations. For fixed devices with geo-location capability operating in a non-adjacent band (i.e. there are no TV transmissions in the adjacent channels), the FCC specifies a maximum EIRP of 36 dBm when an antenna with a gain of 6 dBi is used. Based on this we will assume that each BS sector can transmit with an EIRP of 36 dBm.

FCC also specifies a maximum EIRP of 20 dBm for Portable Personal Devices (PPDs) with geo-location capability operating in non-adjacent bands. OFCOM has indicated a maximum EIRP of 17 dBm for this case [OFCOM2009]. Ofcom's more recent approach has focused on the use of geolocation databases which uses calculations to set maximum EIRPs based on a device's location, rather than setting a fixed EIRP for devices outside of an exclusion zone [OFCOM2012]. Based on this we will use the more restrictive requirement stated by OFCOM and assume that the cognitive LTE user terminal can transmit with a maximum EIRP of 17 dBm.

An inter-site distance (ISD) of 750 meters is typical for macro BS deployments in urban areas. Since the existing BS sites will be used, this will also be the ISD for the cognitive LTE system.

A simulation study was performed to estimate the capacity the cognitive LTE radios can provide. A detailed description is given in Appendix 2.

Figure 7 shows the cumulative distribution function for the BS site capacity for a scenario where a LTE network is located between DVB-T single frequency networks using the same frequency as the LTE network. A detailed description of the scenario can be found in Appendix 2. It can be seen that 50% of the white space area has a site capacity larger than 11.7 Mbit/, and 90% of the area have a capacity larger than 5.7 Mbit/s.

In Appendix 2 it is also shown that it is the downlink that limits the capacity of a cognitive LTE network. This is an expected result when the allowed EIRPs are compared to the EIRPs used in conventional LTE networks. In downlink, conventional LTE networks typically have an EIRP of 60 dBm or more which is significantly more than the 36 dBm a cognitive LTE network can use. However, for uplink the difference is much less. A conventional LTE terminal typically have an EIRP of 23 dBm, which is not that much larger than the cognitive LTE terminal EIRP of 17 to 20 dBm.

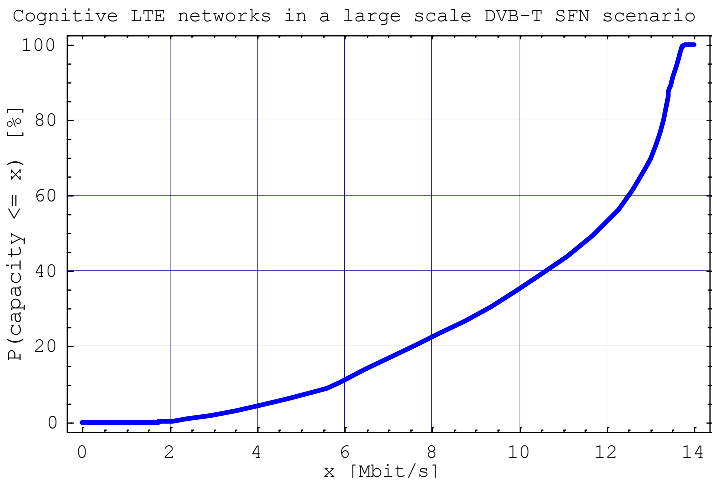

Figure 7 Downlink whitespace site capacity cumulative distribution function for the large area DVB-T SFN scenario

3.4 Assumptions

This section gives the assumptions used in this business case and the motivations behind them. The costs given are for the first year in the study period (i.e. 2015). Then there will be price erosion the following years. Unless stated otherwise, the price erosion is assumed to be 10% per year.

3.4.1 Number of cognitive terminals

It is assumed that the number of subscribers will increase during the study period reaching a total of 100 000 in 2020. Table 3 gives the number of subscribers assumed by the end of the year through the study period for the downtown and suburban areas. The deployment starts in 2015 in the downtown area and in 2016 in the suburban areas.

	2015	2016	2017	2018	2019	2020
Downtown	10 000	15 785	23 371	32 249	41 465	50 000
Suburbs	0	10 000	17 523	27 702	39 188	50 000

Table 3 Number of subscribers at the end of the year in the downtown and suburban areas

3.4.2 Cost of making an eNB cognitive LTE capable

This is the cost to upgrade an existing macro eNB with cognitive LTE capability. The main additions will be a new antenna (4000 €), a new module in the BS rack (2000 €) and installation costs (1000 €). Hence the total cost is estimated to be 7000 €.

3.4.3 Cost of making a conventional eNB support DD2 spectrum

This is the cost to upgrade an existing macro eNB to support Digital Dividend 2 spectrum. The main additions will be a new antenna (2000 €), a new module in the BS rack (1000 €) and installation costs (1000 €). Hence the total cost is estimated to be 4000 €.

3.4.4 Costs associated with the QoSMOS infrastructure

Figure 1 presents the QoSMOS reference model identifying the functional entities as well as their interactions.

The QoSMOS reference model will be used as a basis for estimating the costs of the required QoSMOS infrastructure. However, these costs also depends on the architecture options which is not shown here.

The "cellular extensions in white spaces" scenarios is based on an infrastructure of base stations and will hence have Centralized Resource Control (RRC) as described in deliverable D2.3 [D2.3].

Network coordination:

The "Network Coordination" function coordinates the operation of an operator's networks. Operators having several networks in an area already have this functionality. An example of this is an operator having three parallel LTE networks in an area, operating at 800 MHz, 2.1 GHz and 2.6 GHz respectively. In this case the "Network coordination" function will control the traffic steering and hand over between these layers.

In this case, adding TV white spaces as a new frequency of operation in addition to the other three frequencies will not increase the costs of this component.

Since the most usual case is that operators have more than one network in an area, we will assume that the "Network coordination" functionality do not represent a cost for the operator when adding the cognitive network.

Cognitive manager for spectrum management (CM-SM)

The CM-SM is responsible for building the spectrum portfolio based on the external constraints (regulatory policies, operator policies, etc.) and on spectrum sensing results. The spectrum portfolio contains spectrum usage policies and spectrum usage information, putting constraints on the decisions which can be taken by the other cognitive entities of the QoSMOS system.

The detailed architecture of the CM-SM is presented in [D2.2] section 3.2 including topological and logical models with examples for the mapping of its internal blocks to the TV White Spaces case. Further detailed description of the spectrum management framework is given in [D6.2] addressing context filtering, aggregation and communication functions.

The CM-SM consists of a server and functionality implemented in software. There are several possible models for how such software is priced. We will assume a model where the operator buys the software for a given price. Then there will be a yearly fee that must be paid to the software vendor in order to get support and new releases from them. It will be assumed that this fee is composed of a fixed part and a part proportional to the number of subscribers that are served by this software.

The operator also needs to train its personnel to use the software, and this represents a larger initial cost for the first year and then some yearly costs for updating the competence of its personnel.

We will assume that this is the operator's first cognitive network. In this case, it is expected that the operator wants to adapt the CM-SM algorithms according the operator's policies and strategies. This will represent some developing cost for the operator the first year.

The cost for a powerful server with backup and failover redundancies is estimated to 10 000 €. The software purchasing cost is difficult to assess accurately, but based on experience with software of similar complexity and similar volume we estimate this cost to 100 000 €. Based on the same experience we also estimate the yearly software maintenance fee for this software to be 20 000 €.

To adapt the software to the operator's policies and strategies it is assumed that 3 persons (one programmer, one system expert and one manager) use 80 hours each at an hourly rate of 100 €/hour, resulting in an initial development cost of 24 000 €.

The initial cost for training the operator's personnel in using this software is assumed to be 40 000 €, based on that 10 employees get 1 week of training (40 hours) the first year at an hourly rate of 100 €/hour. The following years it is assumed that 10 employees get 4 hours of training at an hourly rate of 100 €/hour, giving a yearly training cost of 4 000 €.

This gives the following CAPEX and OPEX cost estimates for the CM-SM:

CAPEX	
Server	10 000 €
Software Purchasing costs	100 000 €
Development costs first year	24 000 €
Initial training costs	40 000 €
OPEX	
Software maintenance fee	20 000
Yearly training costs	4 000

It is assumed that the CAPEX costs have a price erosion of 10% per year. No price erosion is assumed for the OPEX costs.

Cognitive Manager for Resource Management (CM-RM)

The main tasks of the Cognitive Manager for Resource Management (CM-RM) is to efficiently support QoS and mobility for wireless networks with intermittently available spectrum resources and to manage the spectrum resources so that incumbent users are not disturbed.

It is expected that the CM-RM functionality will be integrated/added to the functionalities in the network that allocates users to different LTE layers (e.g. LTE at 800, 2100 and 2600 MHz). In fact, the TV white space spectrum will just constitute another LTE layer. However, it will be more challenging to satisfy QoS and mobility requirements in the TV white space layer than in the other layers, so it is expected that the functionality and performance of the LTE layer management must be extended and improved. However, since it is only necessary to extend and improve existing functions, we expect that the associated costs will be low. As the base case we will assume that the required software improvements will be part of the ordinary updates in new releases, and hence will not represent any additional cost for the operator.

Adaptation layer (AL)

The AL enables the collection of information from different RATs through medium specific interfaces and provides a single media independent interface similar to the one exhibited in the IEEE 802.21 standard [IEEE802.21] to the cognitive management entities CM-RM and CM-SM. In addition, it is necessary to convert and analyse measurements and parameters which can be interpreted differently depending on the RAT which is being used, e.g. load levels in access points, SNR limits, etc. The use of the AL eases the management of data fusion for sensing measurement and cooperative sensing in general.

The functions performed by the AL include data conversion, RAT selection, event subscription and message dispatching.

It is assumed that the AL can be implemented as a central server with routing capabilities in addition to AL functionality in the different network elements. The AL functionality in the network elements will be part of those elements' protocols and is not expected to represent additional costs. The cost for a central AL server with backup and failover redundancies is estimated to 10,000 €.

3.4.5 Cost difference between "cognitive LTE" capable terminals and terminals supporting Digital Dividend 2 (DD2) spectrum

It is assumed that the operator has to subsidize the cognitive LTE terminals by an amount corresponding to the price difference between "cognitive LTE" capable terminals and terminals supporting DD2 frequencies (698 – 790 MHz). The study period for the business case starts in 2015 and by then it is assumed that LTE terminals support DD2 frequencies. It is also assumed that price erosion and technological development compensate for the increase in complexity so that the price of LTE terminals (without cognitive capability) will be the same in 2015 as it is today.

Both software and hardware must be added to the user terminals in order to make it capable of cognitive radio operation. A number of new functions have to be implemented, such as the terminal parts of the CM-SM, CM-RM and adaptation layer functions. It is assumed that these functions can be implemented with additional software only and that new hardware like more powerful processors are not needed. With this assumption, it is not expected that the implementation of these functions will represent any additional cost.

Since cognitive radios must be able to operate over large frequency ranges and be very flexible regarding how they operate, e.g. with respect to modulation scheme, forward error correction and power. This requires more complex hardware, e.g. oscillators operating over large frequency ranges, higher resolution analog to digital converts and more powerful base band and RF processing capabilities.

The table below shows the estimated Bill of Materials (BOM) for two smartphones according to a teardown analysis performed by IHS iSuppli Research [IHS2012].

Table 4 Estimated Bill of Materials (BOM) for two smartphones (from [IHS2012])

Preliminary Analysis - And Comparison With Samsung Galaxy SII Skyrocket

Components / Hardware Elements	Nokia Lumia 900	Samsung SII Skyrocket
Retail Pricing (As of April 2012)	**$449.99**	**$549.99**
Total BOM Cost	$209.00	$235.50
Manufacturing Cost	$8.00	$8.00
BOM + Manufacturing	**$217.00**	**$243.50**
Major Cost Drivers		
Memory	$27.00	$32.00
Display & Touchscreen	$58.00	$64.00
Processor	$17.00	$22.00
Camera(s)	$18.00	$20.00
Wireless Section - BB/RF/PA	$38.00	$37.00
User Interface & Sensors & Combo Module (WLAN/BT/FM)	$14.00	$16.50
Power Management	$9.00	$11.00
Battery	$4.50	$5.00
Mechanical / Electro-Mechanical / Other	$18.00	$22.00
Box Contents	$5.50	$6.00

Source: IHS iSuppli Research, April 2012

According to this analysis the wireless section including base band processing costs $38. This is the main part that has to be enhanced in order to make the terminal "cognitive LTE" capable. If it is assumed that the first generation of cognitive LTE terminals will have a wireless section that costs 50% more, the cost for these components will increase by $19 to $57. Since the retail price is about twice the BOM+manufacturing price, the retail price is therefore expected to be about $38 (= 30 €) higher for cognitive LTE terminals than for regular LTE terminals with DD2 support.

3.4.6 Cost of acquiring Digital Dividend 2 spectrum

In the OFCOM report [Aetha] on Spectrum value of 800MHz, 1800MHz and 2.6GHz spectrum, data from recent European awards is used to establish a range for the likely valuation of spectrum in these bands. More specifically for the 800 MHz band, information from the awards in Germany, Sweden, Spain, Italy, Portugal, Denmark and France are given:

Table 5 Spectrum prices obtained in recent European 800 MHz auctions (Converion rate used is £1.00 = 1.25 €)

Country	Price per MHz per capita
Germany	£ 0.714 (0.893 €)
Italy	£ 0.680 (0.850 €)
France	£ 0.519 (0.649 €)
Portugal	£ 0.512 (0.640 €)
Spain	£ 0.460 (0.575 €)
Sweden	£ 0.253 (0.316 €)
Denmark	£ 0.133 (0.166 €)

We will assume that the price for Digital Dividend 2 spectrum will be approximately the same as for 800 MHz spectrum. The mean spectrum price for the auctions given in Table 5 is £ 0.467/MHz/capita, corresponding to 0.584 €/MHz/capita, which will be used as the base assumption.

In “Appendix 2: Capacity of a cognitive LTE system”, the site capacity for a cognitive LTE network was estimated. The capacity was estimated with external co-channel interference from both large area and small area single frequency DVB-T networks. By comparing the two SFN scenarios with the actual DVB-T deployment, e.g. as can be found on interactive web maps like [dvbtmap], the large area SFN scenario seems to be the best model in most areas of Europe today. Hence, this scenario will be assumed in the business case calculations.

In Appendix 2 the site capacity of the cognitive LTE network was found to be higher than 11.7 Mbit/s in 50% of the white space area in the large area SFN scenario. From Figure 32 it can be seen that the site capacity of a LTE network in an external interference free scenario approaches 14.6 Mbit/s for large EIRP values, which is the capacity that will be achieved when LTE is operated in licensed spectrum. Since the bandwidth of the LTE signal used was 7.2 MHz, the spectral efficiency in licensed spectrum will be 2.0 bit/s/Hz. Hence, to achieve a site capacity of 11.7 Mbit/s with conventional LTE in licensed spectrum, a bandwidth of 5.8 MHz is needed.

The estimated cost for 2x5.8 MHz in the city of 1 million inhabitants is then 0.584 €/MHz/inhabitant * 2 * 5.8 MHz * 1000000 inhabitants = 6.8 million €.

3.4.7 Spectrum (geo-location) database fee

The use of spectrum databases today is free, but in the future it is expected that the database operators must charge a fee in order to cover their expenses. A fee might also include economic compensation for the spectrum owners or taxes (for example to partly finance the regulator).

The spectrum database fee is very hard to estimate. As the base case a fee of 5 € per subscriber per year will be used. This is an amount that seems like a reasonable figure seen from the users' point of view.

Due to the uncertainty of this assumption, the sensitivity analysis for this parameter will be very important.

3.5 Business case calculations

3.5.1 Base case results

Table 6 shows a summary of the base case assumptions used for this business case.

Table 6 Offloading of LTE networks business case key value summary

Parameter	Base case assumption (2015)
Cost of making an eNB cognitive LTE capable	7000 €
Cost of making a conventional eNB support DD2 spectrum	4000 €
Cognitive Manager – Spectrum Management (CM-SM)	174 000 € CAPEX 24 000 €/year OPEX
Adaptation Layer	10 000 €
Cost difference between "cognitive LTE" capable terminals and terminals supporting Digital Dividend 2 (DD2) spectrum	30 €
Cost of acquiring Digital Dividend 2 spectrum	6.8 million €
Spectrum (geo-location) database fee	5 €/subscriber/year

Figure 8 shows the cash flows for the cognitive LTE option and the use of Digital Dividend 2 (DD2) spectrum option. The cash flow for the DD2 option is highly negative the first year when the spectrum license is paid, and then very low the following years. In the cognitive LTE case the cash flow is much more flat over the study period.

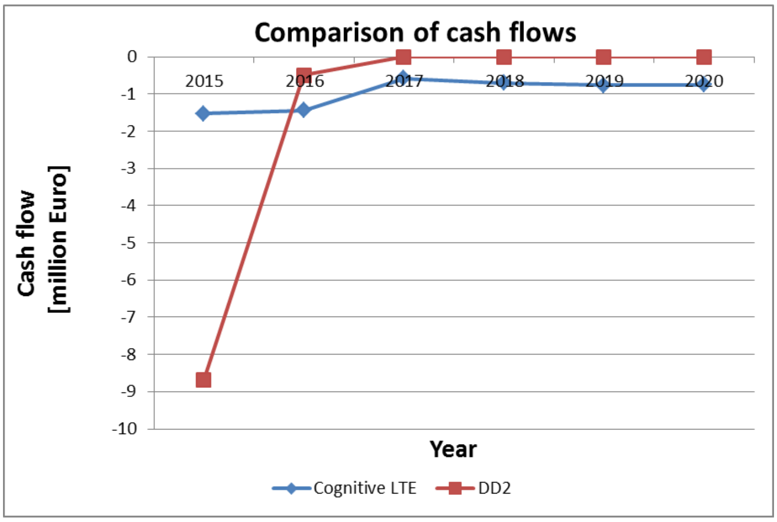

Figure 8 Difference in accumulated cash flow for the cognitive LTE option and the use of Digital Dividend 2 spectrum option. Note that costs and revenues that are common for the two options are not included in the analysis.

The difference between the NPVs is 3.0 million € in favour of the cognitive LTE option.

3.5.2 Sensitivity analysis

3.5.2.1 Sensitivity to spectrum licence cost

A very important and uncertain parameter when comparing the cognitive LTE and Digital Dividend 2 spectrum options is the cost for the spectrum license in the latter case. In fact, this cost totally dominates the Digital Dividend 2 case and any change in this assumption will have great impact on its NPV.

DD2 spectrum cost [mill. €]	NPV difference [mill. €]
0	-3,8
2	-1,8
4	0,2
6	2,2
8	4,2
10	6,2
12	8,2
14	10,2

Table 7 Digital Dividend 2 spectrum cost sensitivity.

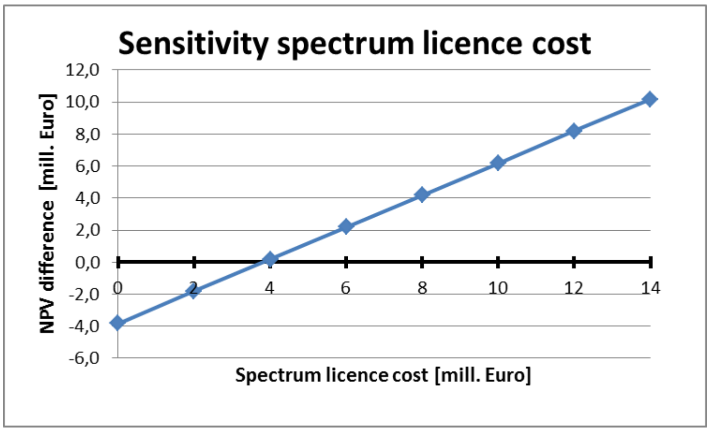

Figure 9 NPV difference between the two capacity offloading options as a function of the Digital Dividend 2 spectrum cost.

The base assumption is that the DD2 spectrum cost is 6.8 million €. This estimate is based on the prices for spectrum in the 800 MHz band obtained in auctions in different European countries. As can be seen in Figure 9 the DD2 business case gets better than the cognitive LTE business case when the cost of the spectrum license drops below about 4 million €. Since the spectrum price varies widely between different markets and the prices depend on factors like economic climate, this parameter is both market and time dependent. Hence, it is important that the operator perform a more thorough analysis for the market in question to obtain a more accurate estimate for the DD2 spectrum cost.

3.5.2.2 Sensitivity to cognitive LTE terminal cost

One of the most difficult parameters to assess was the cost difference between LTE terminals with cognitive capability and LTE terminals with Digital Dividend 2 capability. It is assumed that the operator will subsidize the cognitive LTE terminals so that they will have the same price for the customers. The base assumption is that the operator must subsidize cognitive LTE terminals by 30 € in 2015.

Figure 10 shows the NPV difference between the two options as a function of the LTE terminal cost difference.

Cost difference [€]	NPV difference [mill. €]
0	4,8
15	3,9
30	3,0
45	2,1
60	1,2
75	0,3
90	-0,6
105	-1,5

Table 8 Cognitive LTE terminal cost sensitivity.

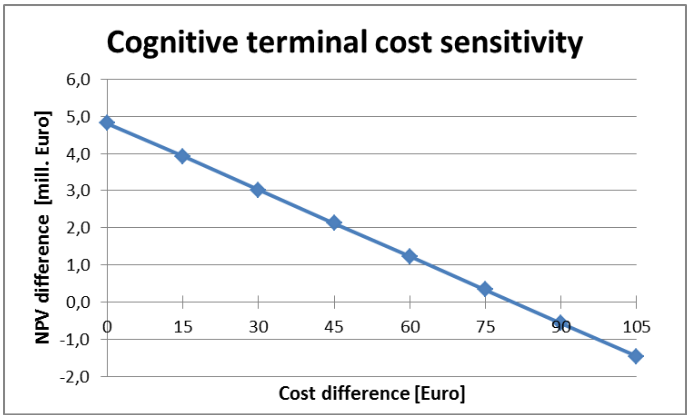

Figure 10 NPV difference between the two capacity offloading options as a function of the LTE terminal cost difference.

As can be seen from Figure 10 the NPV is moderately sensitive to changes in the terminal cost difference.

3.5.2.3 Sensitivity to spectrum database fee

Another uncertain parameter in the business case calculations is the cost of the access to the spectrum geo-location database. The base assumption is that the fee is 5 €/subscriber/year. Figure 11 shows the NPV difference for different spectrum database access fees.

Fee per subscriber per year [€]	NPV difference [mill. €]
0	4,0
2,5	3,5
5	3,0
7,5	2,5
10	2,1

Table 9 NPV difference for different spectrum database access fees

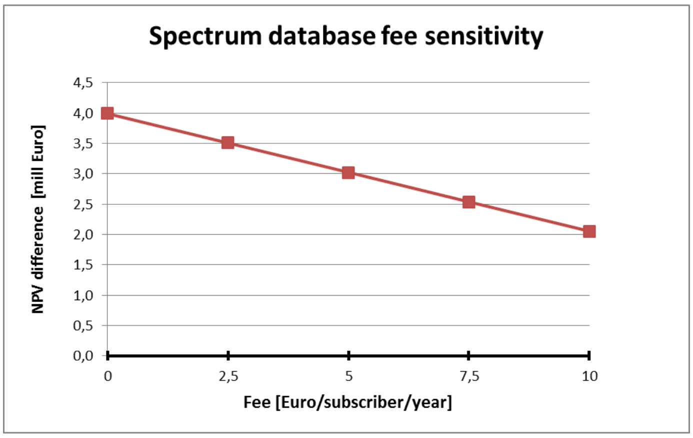

Figure 11 NPV difference for different spectrum database access fees.

The NPV difference is not very sensitive to changes in the spectrum database access fee. For example, if there is no fee the cognitive LTE business case NPV only improves by 1 million €. Hence, the spectrum database fee is not very important for the profitability of this business case.

3.5.2.4 Sensitivity to cost of making an eNB cognitive LTE capable

Both new hardware and software is required in order to upgrade an existing eNB to support cognitive LTE. As a base assumption it is assumed that software does not represent additional costs for the operator. The main hardware costs are for a new antenna and a new module in the BS rack. In addition there will be some installation costs. Based on this a total cost of 7000 € is set as the base assumption.

Figure 12 and Table 10 shows the NPV for different eNB upgrading costs.

Cost for upgrading an eNB [€]	NPV difference [mill. €]
5000	3,5
7000	3,0
9000	2,5
11000	2,0
13000	1,5
15000	1,0

Table 10 NPV difference for different eNB upgrading costs

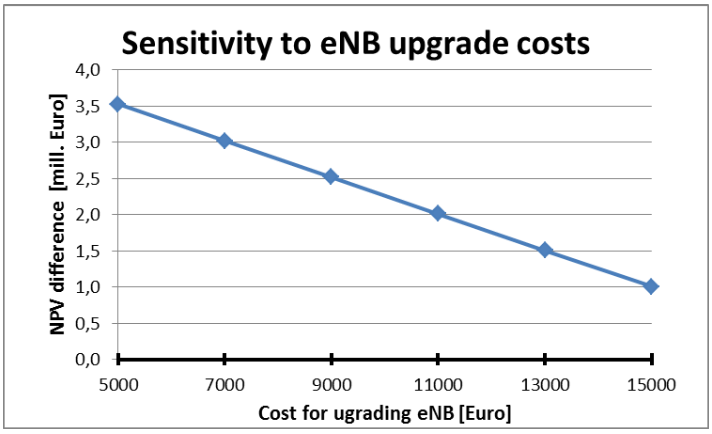

Figure 12 NPV difference for different eNB upgrading costs.

It can be seen from Figure 12 that the NPV difference is not very sensitive to changes in the eNB upgrading costs.

3.6 Business case evaluation

The difference between the NPVs for the cognitive LTE and DD2 options is estimated to 3.0 million € in favour of the cognitive LTE option. Since the technology for the cognitive LTE is not yet developed, many of the assumptions associated with this option are very uncertain. In addition the cost of the Digital Dividend 2 spectrum, which is the dominating cost of the DD2 business case, is very market and time dependent. Hence, it is not possible to conclude that using cognitive LTE is a more cost efficient solution for capacity enhancements than buying more spectrum in a DD2 auction. But the business case study indicates that using cognitive LTE is a possible solution, and that it should be considered as an option. It should also be noted that available spectrum is limited and spectrum sharing will become a necessity to handle expected mobile traffic in the future.

The sensitivity analysis showed that the most important parameter to estimate accurately when deciding which of the two options to choose is the price of the Digital Dividend 2 spectrum. This parameter totally dominates the business case for the DD2 case.

The cost difference between a cognitive LTE terminal and a conventional LTE terminal that supports operation in DD2 spectrum is also a parameter that is important to estimate with good accuracy. However, this parameter is not critical and the cognitive LTE option can still be attractive even if this subsidy cost is somewhat higher than the base assumption.

The attractiveness of the cognitive LTE option is only moderately sensitive to changes in the cost of upgrading an eNB.

The spectrum database fee turns out to have little impact on the profitability of the cognitive LTE option.

4 The “Rural broadband” business case

4.1 Motivation

This business case considers the UK as an example for deploying rural broadband. One of the objetives of the UK governement’s Broadband Delivery UK (BDUK) programme is to deliver broadband with at least 2Mb/s to virtually all UK communities by May 2015 [BDUK2011]. To achieve this broadband must be provided for not-spots. Here, a not-spot is defined as a home that cannot receive broadband with at least 2Mb/s download speeds at peak times. Rural not-spots are those where the length of the wire connecting the home to the main network is typically between 3 and 6 km. Not-spots less than 3 km wire length will be considered as candidates for improved fixed line solutions. There are few not-spots further than 6 km from their nearest exchange. Some of these may be served by this TVWS solution while others may use satellite solutions.

This business case looks at the scenario where a fixed-line operator provides a broadband service to rural not-spots using TVWS. The homes will have roof-top antennas pointing towards the base station.

It should be noted that there is the potential to gain government grants in order to provide broadband to rural areas. These subsidies will not be considered in these business cases.

4.2 Business case description

The business case will be calculated for an Internet service provider to offer a broadband service to rural not-spots using the services of a **fixed line network operator.** The fixed line network operator provides broadband to rural not-spots using TVWS.

The operator will use **TV White Spaces (TVWS)**, i.e. spectrum in the frequency range 470-790 MHz), in a cognitive way to gain the bandwidth required to provide this rural broadband service.

The system would use fixed antennas at both base stations and at the customer end. For this reason there would be no mobility requirement. Thus this solution would be dependent on the QoS capabilities of the QoSMOS project rather than the QoS and mobility capabilities. The base station antenna would be on a short mast at 12m height above ground level while the antenna at the customer end will be at rooftop height of 5m.

Cognitive functionalities, like CM-SM and CM-RM functionality, must be implemented both to terminals and to base stations.

The intention is to base this example business case solely on the **reuse of existing sites** (i.e. no new sites would be needed). The assumption is that these sites are already equipped with the necessary backhaul and power supply capabilities for the rural broadband solution.

The business case is calculated for the UK with a nominal 1 million rural not-spots.

The study period is from 2013 to 2023. The starting year has been chosen based on (a) meeting the targets of the Digital Britain program and (b) when TVWS is expected to become available in the UK, and does not assume the availability of the new QoSMOS TRX equipment, such as FBMC. For this reason the link budget calculations are more conservative, using existing capabilities of LTE.

4.3 Technical considerations

4.3.1 TVWS availability in rural areas

In rural areas not-spots tend to be clustered into groups of around 10 to 30 households. Figure 13 shows how TVWS availability for rural not-spots is calculated from [Kawade2012]. (The analysis in [Kawade2012] is also used for deciding on base values for some of the costs in this example.) On the left of the figure we show the locations of UK not-spots. Arrows show that the rural not-spots correlate well with the UK locations with high estimates of TVWS availability. On the right of the figure we show that the population weighted TVWS availability for rural areas using the same model as used for the map on the left of the figure. The green line represents availability if channels adjacent to occupied TV channels cannot be used; the red line shows the availability if they can. This shows that in rural areas it is a reasonable assumption that in most areas there will be at least 3 channels available.

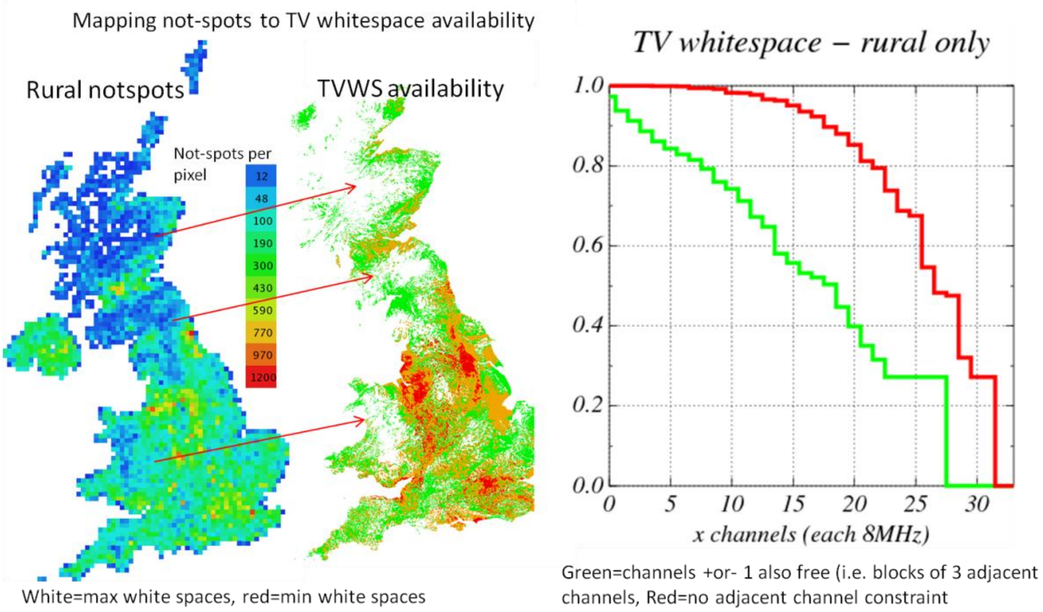

Figure 13 TVWS availability estimates for the UK [Kawade2012]

4.3.2 Number of base-stations required

As this scenario is expected to be deployed before a complete QoSMOS system is available we have used the capabilities of radio front-ends for existing technologies. In this case we consider TD-LTE, although there are alternative standards and technologies available (e.g. WiMAX, Weightless, etc.). We have therefore assumed that only 5MHz of a TV white space channel can be used with an EIRP of 36dBm without interfering with neighbouring channels. The assumed parameter values are shown in Table 11. Using these values, the cell radius that allows for at least 2Mbit/s at the cell edge is approximately 6km. Table 12 shows the required number of base stations required in order to cover the total area of rural non-spots. This assumes a contention ratio of 20:1.

Table 11 TVWS link budget parameters

Parameter	Assumed Value
EIRP (Base station)	36dBm per channel
Base station antenna height	12m
CPE antenna height	5m
Antenna gain	7dBi
Bandwidth	3*5MHz = 15MHz
Noise Figure	8dB

Table 12 Base stations required for varying coverage requirements

Not-spot coverage	20%	40%	60%	80%	100%
Base stations required	1900	3800	5700	7500	9500

In this work near 100% coverage of rural not-spots is targeted so 9500 base stations are assumed to be needed for the TVWS solution.

4.3.3 Roll-out options

In order to meet the BDUK programme's target, to have broadband to virtually all UK communities by May 2015, the service would start roll-out soon; ideally in 2013. A phased roll-out would be planned over the following few years. This allows for revenue to be generated as soon as possible while capital expenditure can be spread over a few years.

4.4 Assumptions

4.4.1 Number of customers

It is assumed that a saturated uptake of customers for rural BB is 1 million.

4.4.2 Phased roll-out and uptake

It is assumed that there will be a phased roll-out of the network infrastructure. The full deployment is expected by the end of year 3, with 40% and 80% deployment achieved by the end of year 1 and 2 respectively. Once an area has infrastructure in place the uptake is expected to follow an s-curve which should reach the saturated number of customers for that area after approximately ten years. After 1 year and 3 years the uptake reaches 35% and 80% of the saturated number of customers respectively.

4.4.3 Revenue per customer

The fact that the target customers are in non-spots means that there are no existing broadband solutions to do a fair comparison. Any existing cellular data service is unlikely to provide a minimum 2Mb/s data rate at peak times and would also likely have a relatively low data allowance. It is possible that the service would be sold at the same prices as broadband is sold in better served areas. This is likely to be a challenging business case as it is the cost margins for typical broadband provisioning are what may make these areas not-spots in the first place. It is possible that customers in not-spot locations are prepared to pay slightly more for a broadband service which can make the business case more appealing to a network provider and ISP.

It is assumed that a customer would pay £30 for rural broadband provided by TVWS. Once the rural broadband service is available in an area it is assumed that customer uptake will follow an S-curve, reaching saturation, for all rural not-spots, of 1 million customers. As there is a reasonably high uncertainty over this value (revenue per customer), this is one of the key values to investigate in the sensitivity analysis study below.

4.4.4 Proprietary solutions

As this business case is planned from 2013, it is unlikely that QoSMOS hardware will be standardised and vendors producing kit. The rural broadband system only requires a subset of the overall QoSMOS functionality; namely the ability to provide QoS in TVWS spectrum, but no mobility is required. As a result deployment, in early phases at least, might use a proprietary solution as standardised products would not yet be available. Future equipment, with more advanced QoSMOS capabilities (lower out-of-band emissions, higher out-of-band rejection and the ability to use fragmented spectrum) could lead to more TVWS availability and could offer higher overall broadband speeds.

4.4.5 Cost of CPE and installation

The CPE device requires that an antenna is installed at roof-top height and aimed towards the correct base station. This installation is only carried out once the customer signs up for the rural broadband service. This installation would require an engineer visit. This cost is considered as part of the CPE costs in the business case which is estimated at £300. This figure could be reduced by charging the customer an initial connection fee. However in this analysis we assume that the network operator covers the entire cost.

4.4.6 Cost of site rental and backhaul

The analysis assumes the use of existing locations for base stations in order to minimise costs. An existing location is a site where an antenna and base station can be installed or fitted which already has the required power and backhaul capabilities. For a single base station location it is assumed that the CAPEX for site rental (antenna installation, rack for base station, power, cooling, service charges etc.) and backhaul is £10k. The annual OPEX for a single site is assumed to be £2k with backhaul at £10k.

4.4.7 Cost of base station

It is assumed that a QoSMOS capable base station for rural broadband would cost approximately £10k. This gives a total CAPEX per site of £20k.

4.4.8 Cost of Cognitive Core network

The core network costs reflect those used for the "Offloading of LTE networks" business case. This has costs for the CM-SM and the adaptation layer. This has a CAPEX of 174k € (£145k) and 34k € (£28k)

4.4.9 Cost of OSS

For this work we have assumed a CAPEX of £1m. The OSS OPEX, together with the core network maintenance, is assumed to total £100k annually.

4.4.10 Cost of Database

As in the other QoSMOS business cases (excluding M2M) it is assumed that each connected device pays an annual subscription fee of 5 € (equivalent to £4).

4.5 Business case calculations

4.5.1 Base case results

Table 13 shows a summary of the values used for this example TVWS solution for rural broadband. The business case calculations are then summarised in Table 14. This business case would require a large capital investment and would have tight margins, the NPV is considered over 10 years. Over ten years, with a discount rate of 10%, this produces a NPV of 115 million €. Figure 14 shows the accumulated cash flow for this example. This shows that cash flow would decrease over the first three years as a result of the phased deployment and gradual uptake of customers in served areas. From year 3, the cash flow would start to increase, becoming positive early in the eighth year.

Table 13 Rural broadband using TVWS key values summary

Name	**Value**
Number of base stations required	9500
ARPU	£30 (37.50€) per month
Annual discount rate	2%
CPE + installation	£300 (375€)
Client side maintenance	£50 (62.50€) per year
Base station site rental / maintenance and backhaul	£12 000 (15 000€)
Geolocation database	£4 (5€) per device per year
Core/OSS maintenance	£100 000 (125 000€) per year
Base station + installation	£20 000 (25 000€)
QoSMOS core network fixed costs	£200 000 (250 000€)
OSS integration	£1m (1.25€)

Table 14 Rural broadband using TVWS business case summary

	Year									
Values (million €)	1	2	3	4	5	6	7	8	9	10
Revenues	32	115	218	304	356	381	388	386	381	375
OPEX	62	133	179	195	205	210	213	214	215	215
EBITDA	-31	-18	39	109	151	170	175	172	166	160
CAPEX	123	166	139	80	52	29	14	6	2	1
Cash flow	-153	-185	-100	30	99	141	161	166	164	159
Accumulated cash flow	-153	-336	-434	-401	-298	-152	13	184	353	517

Year	Accumulated cash flow [million €]
1	-153
2	-336
3	-434
4	-401
5	-298
6	-152
7	13
8	184
9	353
10	517

Table 15 Accumulated cash flow for rural broadband using TVWS

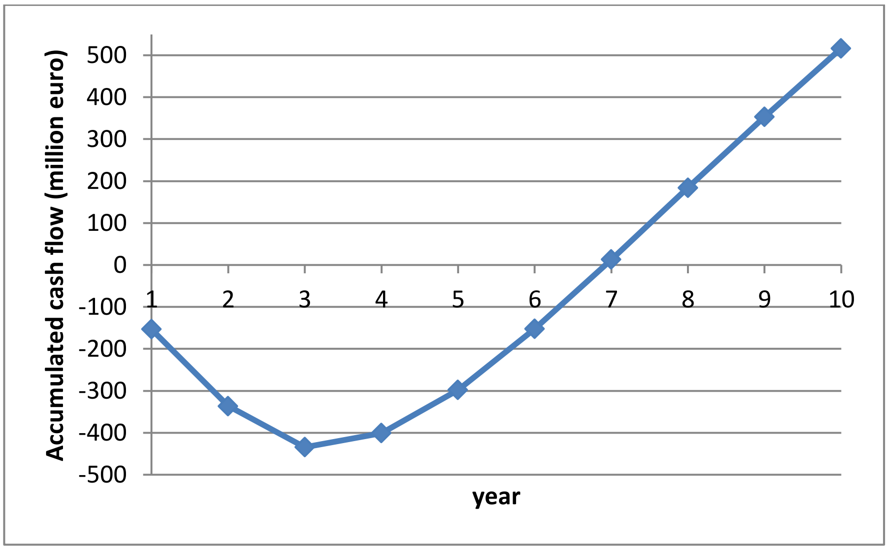

Figure 14 Accumulated cash flow for rural broadband using TVWS

4.5.2 Sensitivity analysis

4.5.2.1 Sensitivity to number of customers

Figure 15 shows what the sensitivity would be to the saturated number of customers. The base assumption of 1 million would give an NPV of 115 million €. The NPV becomes negative for less than around 900 000 customers. If the number of customers were as low as 400 000 the NPV would be -599 million €. If the number of customers were as high as 1.4 million the NPV would be 590 million €. This shows that the success or failure of this TVWS solution would be extremely sensitive to the number of customers. If the number of customers were lower than the assumed 1 million, then this could be due to lower than expected uptake. However, if it were due to fewer not-spots being targeted with this solution then less infrastructure would be needed. If this was the case then a much lower capital investment would be required meaning the business case would be stronger than the figure shows.

Number of customers [millions]	NPV [million €]
0.4	-599
0.6	-361
0.8	-124
1.0	115
1.2	353
1.4	590

Table 16 Sensitivity to number of customers

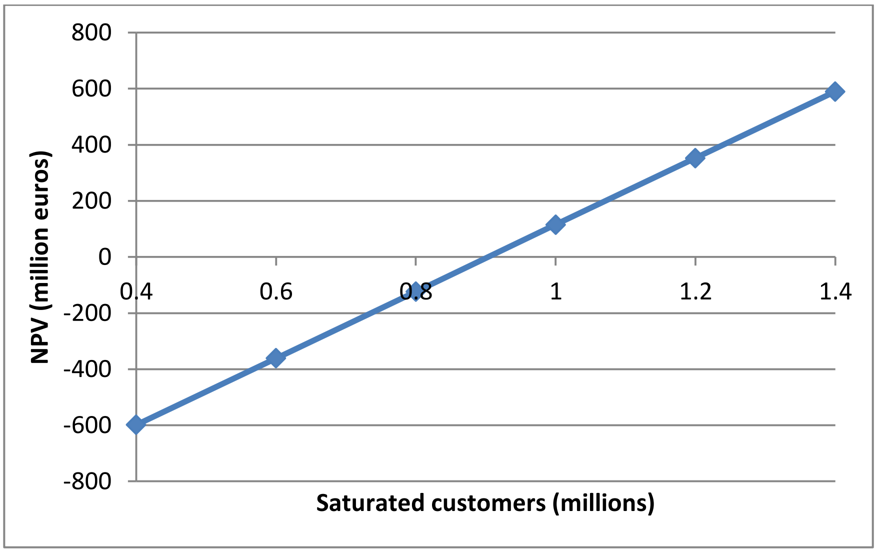

Figure 15 Sensitivity to number of customers for rural broadband using TVWS

4.5.2.2 Sensitivity to revenue per customer

Figure 16 shows what the sensitivity would be to the average revenue per customer. The base value is 37.5 € per month. The NPV would become negative when the revenue per customer falls below approximately 35 € per month. If the revenue per customer were as low as 25 € per month the NPV would be -478 million €, yet if the revenue per customer were as high as 44 € per month the NPV would be 411 million €. This shows that the average revenue per customer would be another key variable for this example business case.

Monthly revenue per customer [Euros]	NPV [million €]
25.00	-477
28.13	-330
31.25	-181
34.38	-34
37.50	115
40.63	262
43.75	411

Table 17 sensitivity to revenue per customer

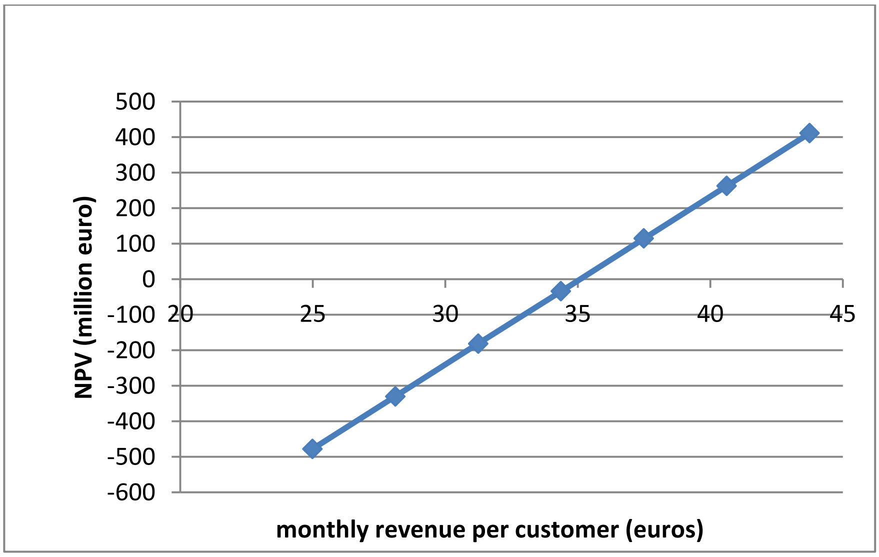

Figure 16 Sensitivity to revenue per customer for rural broadband using TVWS

4.5.2.3 Sensitivity to CPE cost

Figure 17 shows what the sensitivity would be to a change in the cost of the CPE and its installation. The base value assumed was 375 €. If the cost were as high as 500 € the NPV would drop as low as 16 million €. If however, the cost were lower (this may be due to lower CPE costs or due to the customer covering some or all of this cost as a setup fee). In the extreme value that the customer covers all of this cost, the NPV would be as high as 408 million €.

CPE cost + installation [Euros]	NPV [million €]
0	408
62.50	359
125.00	310
187.50	261
250.00	213
312.50	164
375.00	115
437.50	66
500.00	16

Table 18 Sensitivity to CPE cost

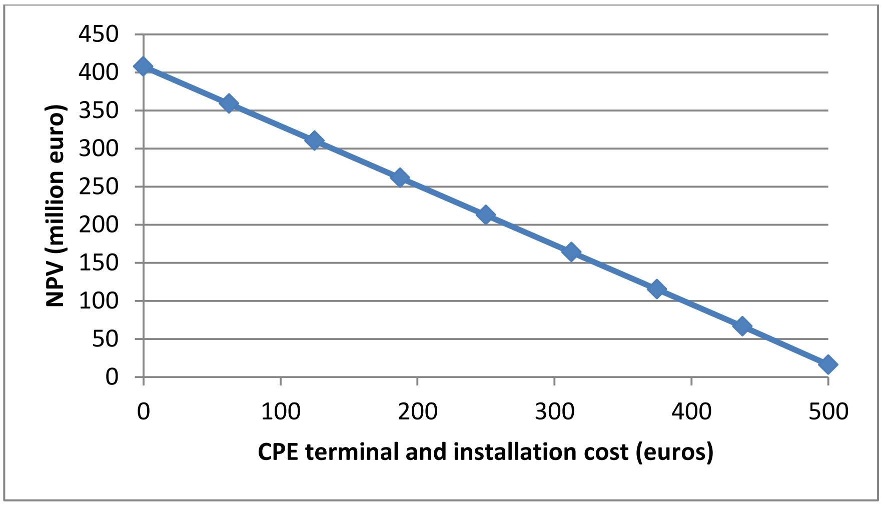

Figure 17 Sensitivity to CPE + installation cost for rural broadband using TVWS

4.5.2.4 Sensitivity to database subscription fee

Figure 18 shows what the sensitivity would be to the database subscription fee. The base value was assumed to be 5 € per year. If a fee as large as 10 € were charged per year, then the NPV would fall as low as 93 million €. If there was no database fee at all, then the NPV would rise to 136 million €. This shows that the business case would be less sensitive to a variation in database fee than some of the other variables evaluated in this example. For TVWS devices to be deployed this database fee could be considered as the only spectrum cost for the use of TVWS. We have considered 0 up to 10 € per year as the range of charges which might be applied for a rural broadband solution. If however, this cost per device were much higher, the NPV would fall further and could become negative. This highlights the cost benefit of the use of TVWS compared to licensed spectrum when spectrum licenses are likely to be higher than database subscription costs.

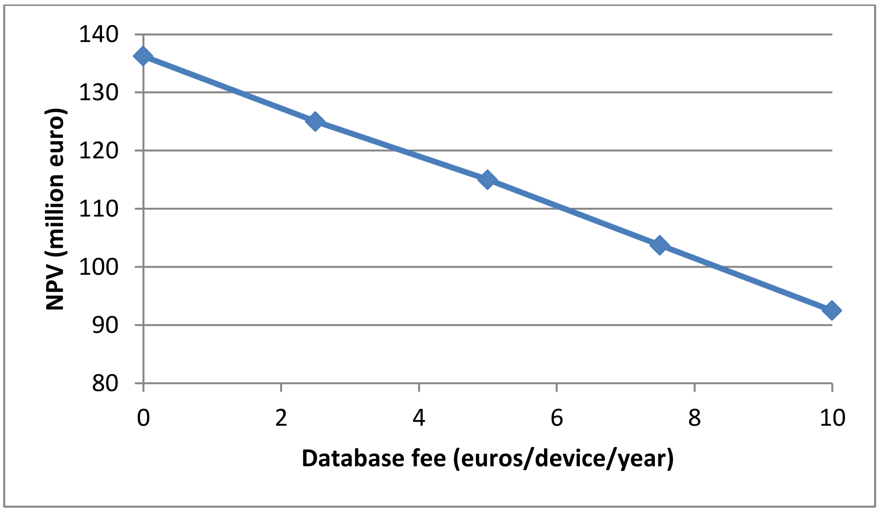

Figure 18 Sensitivity to database subscription fee for rural broadband using TVWS

Database annual fee [Euros]	NPV [million €]
0	136
2.50	125
5.00	115
7.50	104
10.00	93

Table 19 Sensitivity to database fee

4.6 Business case evaluation

The results show that over ten years the TVWS solution would be positive. However, the sensitivity analysis shows that the business case would be highly sensitive to (a) the revenue that could be charged per customer and (b) the number of customers that would subscribe to this service. This risk can be expected as this business case looks to provide a service in not-spots; areas where, up until now, it might not have been economically viable to provide an adequate broadband service. For such areas, the TVWS may be the best or cheapest technical option. As such, any network operators with a legal obligation for such coverage might still be attracted to the solution even if the NPV were negative. Also, further incentives could be provided by local or national government programmes who wish to encourage increased broadband coverage to underserved areas.

Another key variable would be the cost of the CPE and installation. If this cost were lower or the customer could bear some of the cost as a setup fee then the business case could be much stronger. The sensitivity analysis showed that the business case would be less sensitive to changes in an annual database subscription cost.

It is also worth noting that this business case only looks at the revenue that could be gained through a basic broadband service (2Mb/s at peak times). Upgrades to the existing infrastructure or higher permitted transmit powers could provide much higher capacity broadband which could make the business case stronger or more future-proof. There are also a growing number of services that require an existing broadband connection (e.g. video on demand). This business case has ignored the additional revenues that could be gained by these add-on services once not-spots have broadband coverage.

5 The “Cognitive femtocell” business case

5.1 Motivation

One of the trends that can be seen in the market today is that fixed broadband operators loose market shares. The bitrates offered by mobile broadband has now increased to a level where it gives sufficient capacity to be an option to fixed broadband for many users. Since many customers already have smart phones with mobile broadband subscriptions, it might be economically beneficial for them to terminate their fixed broadband contracts and use mobile broadband also for providing internet connection to their home.

One way for fixed operators to avoid this trend is to offer their customers a mobile broadband service in addition to the fixed broadband service. In this way the fixed operators will both keep the customers and increase their ARPUs.

However, it is well known that it is very expensive to build mobile infrastructures and very difficult to compete with existing operators having already done their infrastructure investments. Hence, building a new mobile network involves large investments and big risks, and will not be an attractive solution for fixed operators. Another possibility is to become a MVNO (Mobile Virtual Network Operator), but then the prices for the mobile service will be based on the costs of the mobile network owner and it will be difficult to compete with traditional mobile operators.

An alternative approach, which makes it possible to exploit the fixed network infrastructure for the mobile service, is to base the mobile service on cognitive femtocells. Cognitive femtocells are small LTE base stations giving coverage within and in a small area around the home or office where it is placed.

The fixed operator is assumed to have an existing infrastructure (i.e. fibre, cable, ADSL or fixed wireless), and it will use this infrastructure in combination with cognitive femtocells to offer its customers mobile broadband at home. That is, customers signing up for the mobile service will be given a cognitive femtocell which they mount in their home or office. When the customers use their mobile devices at home/office they will connect to the cognitive femtocell. From experience it is known that a large part of the traffic from a subscriber is generated while the subscriber is at home or in his or her office, and this traffic will then go in the fixed operator’s own network. In addition, customers can also use other customers’ femtocells when they are within coverage of one or more of these. In order to provide full coverage to its customers, the fixed operator will establish roaming agreements with traditional mobile broadband operators.

The fixed operator will only earn money when the mobile traffic goes over the cognitive femtocells. In the beginning, this will be the traffic generated when the subscribers are near their homes since the coverage provided by other customers’ cognitive femtocells will be small. But as the number of customers having cognitive femtocells increase, more and more of the mobile broadband traffic will be carried by the fixed operator’s own network instead of being carried by other mobile operators’ networks. Hence, the fixed operator will gradually get more of the income from its customers’ mobile traffic.

Eventually, the fixed operator will have a dense network of cognitive femtocells which can serve as a basis for further expansion. In a longer perspective, it can be interesting to complement this network by adding small cells (e.g. picocells and microcells) to improve the coverage and capacity of the network. This might give continuous coverage and the roaming agreements will no longer be necessary. This is however not included in this assessment.

It is expected that the need for mobile broadband capacity will increase dramatically in the coming years, and that an extensive use of small cells is required to meet this demand. This means that traditional mobile operators also have to build a large number of small cells and that a large part of their traffic will be carried by these. Then, in a larger perspective, the approach used by the fixed operator by starting the mobile network deployment with small cells and gradually increasing the coverage and capacity as the number of cells grow can be seen as an option to the traditional way of starting with large cells to provide coverage and then complement with small cells to keep up with the capacity demand.

5.2 Business case description

The business case will be calculated for a **fixed network operator**. This operator is one of the leading fixed network operators in the studied area/country. It has a large market share in fixed broadband based on e.g. DSL and FTTH solutions. It has an extensive cable, transport and switching infrastructure and an existing organisation for sales, marketing, technology and operation.

The operator will use **TV White Spaces** (i.e. vacant spectrum in the frequency range 470-790 MHz) in a cognitive way to extend its business to include also **mobile** (voice and) broadband services. The idea is that by cognitive operation the range of a femtocell can be increased to cover also outdoors areas nearby the home or office where it is located. The fixed operator has the advantage that it already provides fixed broadband to a large number of customers, which can be used as backhaul for the customers' femtocells. The large majority of the customers already have a Wi-Fi-router provided by the fixed broadband operator connected to the fixed broadband. For customers also signing up for the mobile broadband service, these can be replaced by femtocells or hybrid devices which include modems for fixed broadband, Wi-Fi and femtocell operation.

The main advantage of this solution for the fixed operator is that it can extend its business towards mobile services without acquiring spectrum licences. It can utilize its own infrastructure and the existing customer relations.

Fixed operators using this solution must compete with mobile operators. Therefore QoS and mobility must be as good as in traditional mobile broadband.

Depending on the regulatory rules, the fixed operator might have to acquire a license for secondary cognitive use of the spectrum. But this will take less time and be cheaper than acquiring a traditional spectrum license. In this business case it will be assumed that the fixed operator do not have to pay for a secondary licence.

Because the cognitive femtocells cannot, especially in the start phase, provide good coverage all over the targeted area, it will be necessary that the fixed operator has a **roaming or MVNO** agreement with one (or more) of the existing mobile operators.

The business case is calculated for a hypothetical western European city with 1 million inhabitants covering an area of 200 km^2. The city has a downtown area which covers 50 km^2 with 0.5 million inhabitants and an urban/suburban area which covers 150 km^2 also with 0.5 million inhabitants.

The study period is from 2015 to 2020. The starting year has been chosen based on when it is expected that the concept is sufficiently mature both with respect to technology and business aspects.

5.3 Assumptions

5.3.1 Average revenue per user

To estimate the subscription fee that can be charged for the cognitive femtocell based service, a comparison with the corresponding fee for mobile broadband services will be made. The main use of both the cognitive femtocell service and the mobile broadband service will be for providing Internet connectivity for different types of terminals. The subscribers will experience a conventional mobile service and the femtocell based service as virtually equal. The cognitive femtocells might be able to offer higher capacities if the network get access to larger amounts of cognitive spectrum, but this difference might not be significant if the conventional mobile network also offers femtocells to the subscribers. However, we will assume that the fixed operator's subscribers will need an incentive to choose the femtocell based mobile service over a conventional mobile service, and that this incentive will be in the form of somewhat cheaper subscriptions.

To find what a typical unbundled mobile broadband subscription rate could be, a simple survey of prices offered was done in October 2012. Table 20 gives the results of the survey. The minimum and maximum subscription rates are 24.99 and 40.60 € / month respectively. The average rate is 31.3 € / month.

Table 20 Examples of mobile broadband prices in Western Europe in October 2012

Operator	Country	Subscription rate	Data allowance
T-Mobile	UK	£25.99 / month (32.40 € / month)	Unlimited
T-Mobile	Germany	30 € / month	3GB/month
Telenor	Norway	299 NOK/month (40.60€ / month)	10 GB/month
Telia	Sweden	299 SEK/month (34.70€ / month)	20 GB/month
SFR	France	24.99€ / month	500 MB/month

It will be assumed that there is a moderate yearly reduction of the subscription fee. This reflects the trend that operators often choose to increase the performance parameters (e.g. the throughput and data allowance) and keep the fees fixed. However, some reduction should still be expected due to competition. We will assume an average yearly reduction of the subscription fees of 2%. We thus expect the average mobile broadband subscription fee to be about 29.5€ in 2015.

The subscription rate for the cognitive femtocell based service is expected to lower than for a conventional mobile broadband service. The subscribers get a combined subscription for the operator's fixed and mobile services, and it is the increase in subscription fee that matters for this business case calculations. It will be assumed that the increase in subscription fee to include the mobile service will be 20€, which is 32% lower than the estimated average subscription fee for mobile broadband services in 2015.

5.3.2 Number of cognitive femtocells

It is assumed that the number of subscribers with a cognitive femtocell will increase during the study period reaching a total of 100 000 in 2020 equally divided between the downtown and suburban areas. It is further assumed that there will be two subscribers per household on average, hence the total number of cognitive femtocells will be 50 000 in 2020. Table 21 gives the number of cognitive femtocells assumed by the end of the year through the study period for the downtown and suburban areas. The deployment starts in 2015 in the downtown area and in 2016 in the suburban areas.

Table 21 Number of cognitive femtocells at the end of the year in the downtown and suburban areas

	2015	2016	2017	2018	2019	2020
Downtown	2 500	5 423	10 128	15 882	21 172	25 000
Suburbs	0	2 500	6 439	12 965	19 966	25 000

5.3.3 Cost of a cognitive femtocell

The shop price of a good dual band (2.4 and 5 GHz) 802 .11n router is about 150 € today. 3G femtocells are sold by operators for 50 € or less, but this is subsidized prices. The actual cost of the 3G femtocells are not known since both operators and vendors consider this as confidential information, but it is probably 2 or 3 times higher (i.e. 150-200 €). The complexity of a cognitive femtocell will be higher than that of an 802.11n router and a 3G femtocell taking into account that it must operate over a larger frequency range and have the functionality required to interwork with the operator's core network. However, since it is the cost in three years' time (i.e. in 2015) that must be estimated, it is expected that the technical development will partly compensate for this increase in complexity. It will be assumed that the price of a cognitive femtocell in 2015 will be 50% higher than the price of a 802.11n router or 3G femtocell today, i.e. 225 €.

5.3.4 Cognitive femtocell installation costs

It is expected that operators want to avoid having to send a service engineer to install cognitive femtocells since this will represent a significant cost. It is therefore assumed that the operator will use self-installable cognitive femtocells. Hence, the base assumption is that there will be no installation costs.

5.3.5 Cognitive functionality in core network

The fixed operator must include the cognitive functionalities as given by the QoSMOS architecture (see Figure 1) in his core network. This includes the CM-SM, CM-RM and adaptation layer.

The same assumptions will be used as in the "Offloading of LTE networks" business case given is section 3.4.4.

5.3.6 Cost of mobile core network components

The fixed network operator must add mobile network elements to its network. The main components will be the Serving Gateway (SGW), the Packet Data Network Gateway (PGW), Mobility Management Entity (MME) and Home Subscriber Server (HSS). The cost for these components is assumed to be 200 000 €.

5.3.7 Cost of cognitive capabilities in terminal

It is assumed that the fixed operator has to subsidize the cognitive LTE terminals by an amount corresponding to the price difference between a "cognitive LTE" capable terminal and an ordinary LTE terminal in order to make the service attractive.

In section 3.4.5 this cost difference was estimated to be 30 €.

5.3.8 Spectrum (geo-location) database fee

The same fee as assumed in the “Offloading of LTE networks” business case given is section 3.4.4 is used, i.e. 5 € per subscriber per year.

5.3.9 General OPEX per customer

The additional general OPEX cost per mobile broadband customer. The general OPEX covers e.g. customer acquisition (sales and marketing) costs and general operations of the company. Its value is highly uncertain and difficult to benchmark due to different accounting principles in different companies and countries.

It is assumed that the fixed operator will have an extra marketing cost of 1 million € the two first years (i.e. 0.5 million per year). It is also assumed that the increase in general OPEX per customer for the fixed operator is 10 €/Month/customer in 2015, then reduced by 10% the first two years and 15% the next years.

5.4 Business case calculations

5.4.1 Base case results

Table 22 shows a summary of the base case assumptions used for this business case.

Table 22 Cognitive femtocell business case key value summary

Parameter	Base case assumption (2015)
Average revenue per user	20 €
Cost of a cognitive femtocell	225 €
Cognitive femtocell installation costs	0 €
CM-SM	174 000 € CAPEX, 24 000 €/year OPEX
Adaptation Layer	10 000 €
Cost of mobile core network components	200 000 €
Cost of cognitive capabilities in terminal	30 €
Spectrum (geo-location) database fee	5 €/subscriber/year
General OPEX per customer	10 €/Month/customer plus an extra marketing cost of 1 million € the two first years (i.e. 0.5 million per year).

Figure 19 shows the accumulated cash flow for the study period. As can be seen, this appears to be a reasonable business case. The investments the first years are moderate since the fixed infrastructure is already there and the initial investments that the fixed operator must do are for the mobile core components. The large marketing expenses the first years contribute significantly to the negative cash flow in this period.

The NPV for the study period 2015-2020 is 4.5 million €.

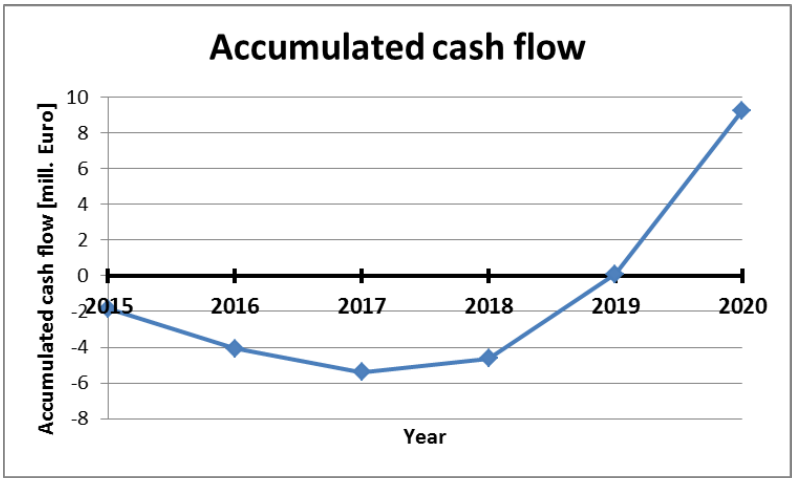

Figure 19 Accumulated cash flow for the cognitive femtocell business case using the base assumptions.

5.4.2 Sensitivity analysis

Sensitivity analysis is done here by changing the value of one (critical) input parameter and showing how the economic results are changing. All other input parameters are as in the "Base case". NPV is used as the indicator of profitability.

5.4.2.1 Sensitivity to the "Average Revenue per User (ARPU)"

The only revenue that is considered in this business case is that coming from the subscription fees. Hence, it should be expected that the profitability of the business case heavily depends on this parameter.

Figure 20 and Table 23 shows the sensitivity of the NPV to ARPU in 2015. It is further assumed that the ARPU decreases by 2% each year.

ARPU [€/Month]	NPV [mill. €]
10,0	-13,0
15,0	-4,3
20,0	4,5
25,0	13,3
30,0	22,1
35,0	30,9
40,0	39,7

Table 23 Sensitivity to ARPU (2015).

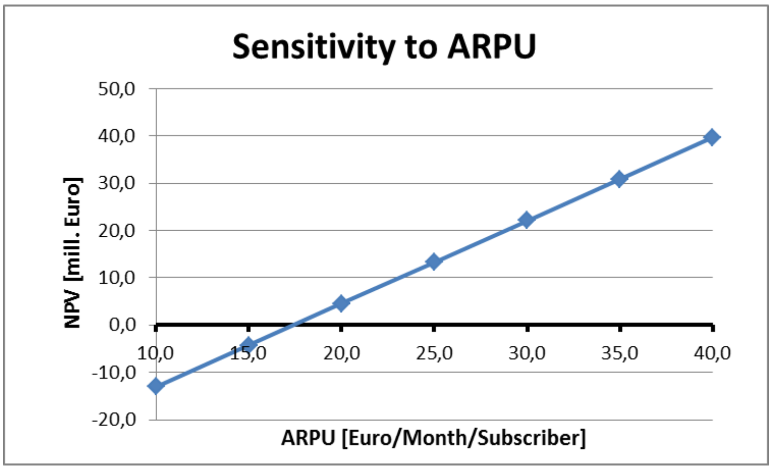

Figure 20 Sensitivity to ARPU

The base assumption is that the ARPU is 20 €/month/subscriber in 2015, which is somewhat lower than current typical mobile broadband subscription fees. If the ARPU falls below about 17 €, which is within the uncertainty range of the estimate, the NPV gets negative. Hence, this is clearly a very critical parameter for the business case.

5.4.2.2 Sensitivity to increase in general OPEX costs

The fixed operator will get an increase in the general OPEX costs for its customers that subscribe to the mobile service as well.

The increase in general OPEX cost is an uncertain parameter which to a large degree depends on how well the company is run. Table 24 and Figure 21 show the sensitivity to the increase in general OPEX costs in 2015.

Increase in general OPEX costs [€/subscriber/month]	NPV [mill. €]
0,0	23,8
5,0	17,4
10,0	10,9
15,0	4,5
20,0	-1,9
25,0	-8,3
30,0	-14,7

Table 24 Sensitivity to increase in general OPEX costs.

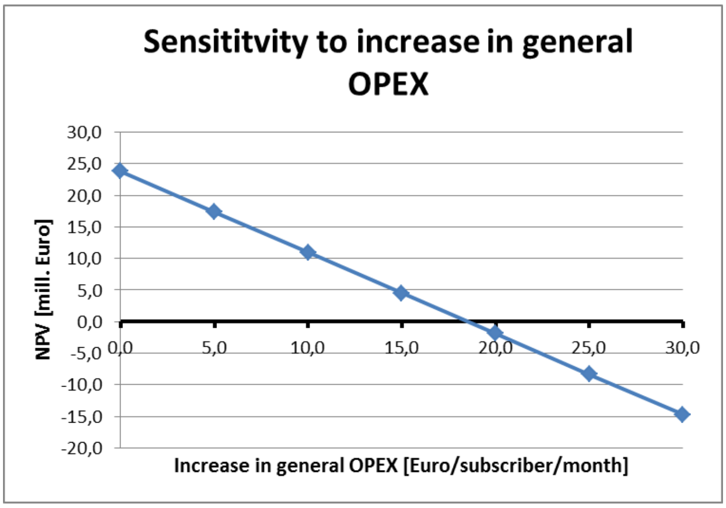

Figure 21 Sensitivity to increase in general OPEX costs.

It can be seen that the profitability of the business case is indeed very sensitive to the increase in general OPEX. For example, if the general OPEX is increased from 15 to 18.5 €/subscriber/month, the

NPV gets negative. Hence, it is important for the fixed operator to evaluate if the economic resources that the business case allows to use on marketing are sufficient for obtaining necessary number of mobile subscribers.

It should be noted that this parameter does not depend on the QoSMOS concept.

5.4.2.3 Sensitivity to increase in cognitive terminal cost

It is assumed that the fixed operator subsidizes the cognitive LTE terminals so the customers will have to pay the same for these terminals as for conventional LTE terminals. The cost difference between cognitive and conventional LTE terminals is difficult to estimate accurately since the cognitive technology is not yet developed.

Figure 22 and Table 25 shows the sensitivity of the NPV to increases in the cost of the cognitive LTE terminal.

Increase in terminal cost [€]	NPV [mill. €]
0,0	6,2
15,0	5,4
30,0	4,5
45,0	3,7
60,0	2,8
75,0	2,0
90,0	1,1

Table 25 Sensitivity to increase in terminal cost

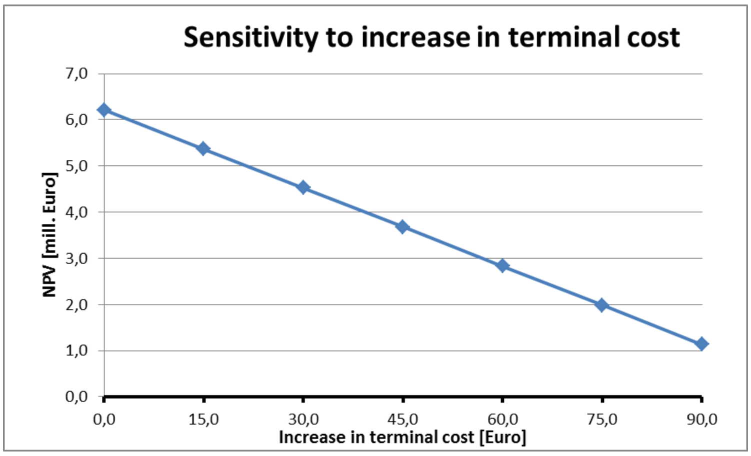

Figure 22 Sensitivity to increase in terminal cost

The base assumption is that the fixed operator must subsidize the cognitive LTE terminals by 30 € in 2015. Figure 22 show that a doubling or even tripling of this amount does not make the NPV negative. Hence, it can be concluded that this is not a critical parameter.

5.4.2.4 Sensitivity to the cost of the cognitive femtocell

The cost of the cognitive femtocell is an uncertain parameter since much of the required technology is not yet developed. Table 26 and Figure 23 show the sensitivity of the NPV to this cost.

Cost of cognitive femtocell [€]	NPV [mill. €]
75,0	9,4
125,0	7,8
175,0	6,2
225,0	4,5
275,0	2,9
325,0	1,3
375,0	-0,4
425,0	-2,0

Table 26 Sensitivity to the cost of the cognitive femtocell

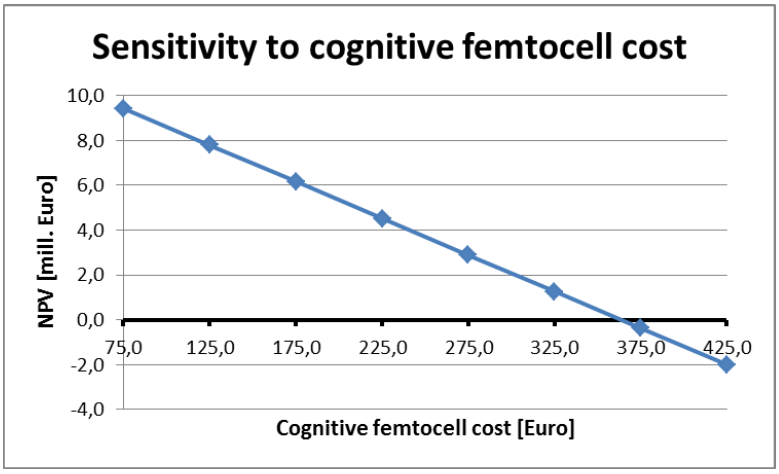

Figure 23 Sensitivity to the cost of the cognitive femtocell

The base assumption is that the cognitive femtocell will cost 225 € in 2015. Figure 23 shows that the NPV gets negative if the femtocell costs more than about 363 €.

Given the great uncertainty of this parameter, the fixed operator should do a more thorough study to get a more accurate estimate of the cognitive femtocell cost. Reducing the cost of cognitive femtocells is also one of the topics that should be targeted in research and development work.

5.4.2.5 Sensitivity to cognitive femtocell installation costs

The base case assumption is that the cognitive femtocells are “Plug’n’Play” devices that the subscribers will install themselves. In practise some of the customers need to get the femtocell installed by a service engineer. If the reason is that the customer doesn’t want to or is not able to install it, it is reasonable that the customer pays the installation costs. These cases will not have any influence on the business case. But in some case it might be the fixed operator that wants to install the cognitive femtocell, for example to maximize its outdoor coverage.

Figure 24 and Table 27 show the sensitivity to average cognitive femtocell installation cost in 2015.

Average cognitive femtocell installation cost [€]	NPV [mill. €]
0,0	4,5
20,0	3,8
40,0	3,1
60,0	2,4
80,0	1,7
100,0	1,0

Table 27 Sensitivity to average cognitive femtocell installation costs.

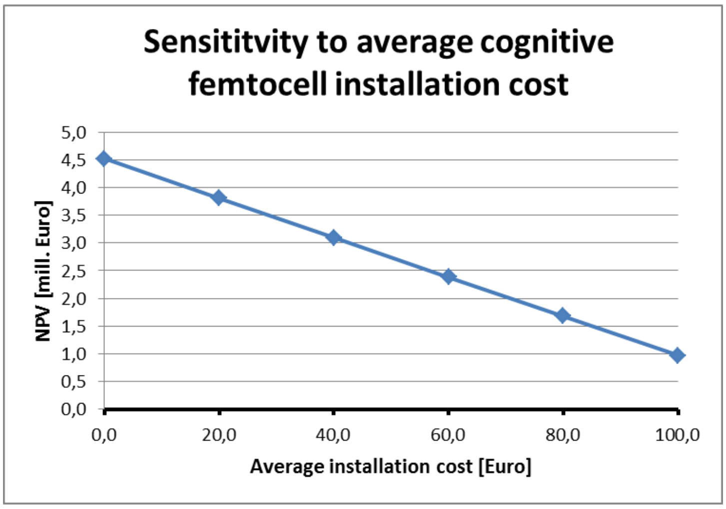

Figure 24 Sensitivity to average cognitive femtocell installation cost.

It can be seen that the profitability of the business case is moderately sensitive to the average installation cost. Even if the installation cost is as high as 100 €, which could be a realistic value if the installation was always done by a service engineer, the NPV remains positive.

5.4.2.6 Sensitivity to the cost of the mobile core network

To make it possible to offer a mobile service the fixed operator must complement its core network with the necessary mobile core components. The base assumption was that this represented a cost of 200.000 €.

Figure 25 and Table 28 show the sensitivity of the NPV to the cost of the mobile core network.

Cost of mobile core network [thousand €]	NPV [mill. €]
100,0	4,6
200,0	4,5
300,0	4,4
400,0	4,3
500,0	4,2
600,0	4,1
700,0	4,0

Table 28 Sensitivity to the cost of the mobile core network

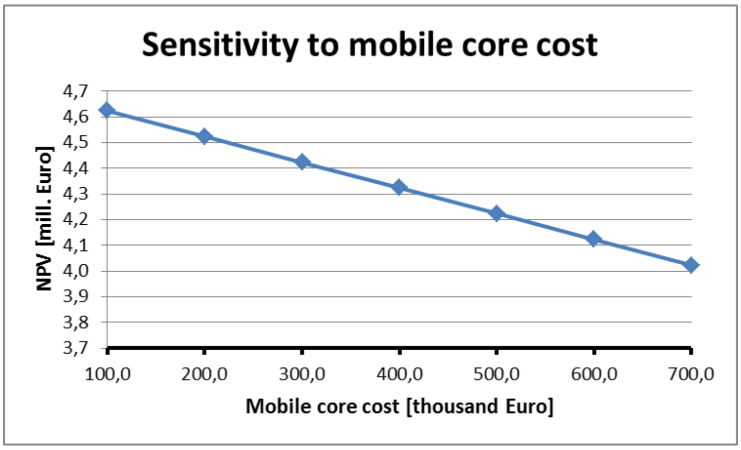

Figure 25 Sensitivity to the cost of the mobile core network

It can be seen that a doubling or tripling of this cost does not have a significant impact on the profitability of the business case. Hence, it can be concluded that this is not a critical parameter.

5.4.2.7 Sensitivity to spectrum database fee

Table 29 and Figure 26 show the sensitivity to the spectrum geo-location database fee.

Spectrum database fee [€]	NPV [mill. €]
0,0	5,4
1,0	5,2
2,0	5,0
3,0	4,9
4,0	4,7
5,0	4,5
6,0	4,3
7,0	4,2
8,0	4,0
9,0	3,8
10,0	3,7

Table 29 Sensitivity to spectrum database fee.

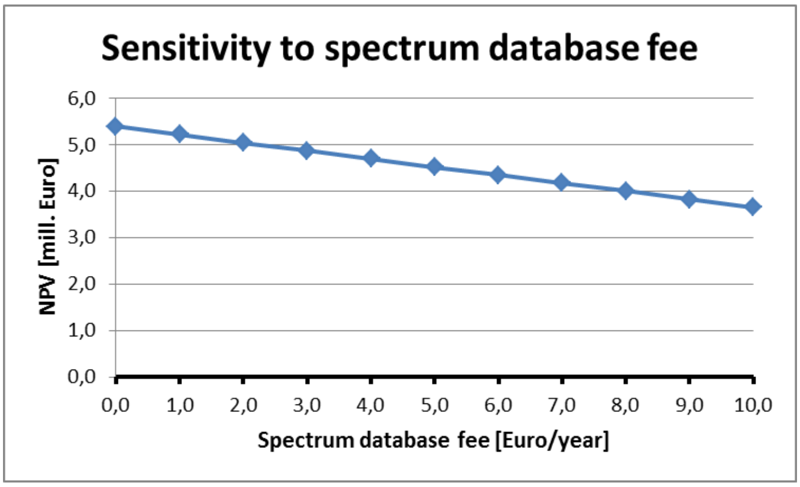

Figure 26 Sensitivity to the spectrum database fee.

The NPV is not very sensitive to changes in the spectrum database access fee. For example, if there is no fee the cognitive LTE business case NPV only improves by 15%. Hence, the spectrum database fee is not very important for the profitability of this business case.

5.4.2.8 Sensitivity to femtocell downtown coverage range

The femtocell coverage range is an important parameter since it determines what the total coverage of the fixed operator's population of femtocells will be. If the coverage is low, a large part of the mobile traffic will go over other mobile operators' networks. Since the fixed operator only earns money when the traffic goes over the femtocells, this will significantly influence his revenues.

Figure 27 and Table 30 shows the sensitivity to the femtocell downtown coverage range.

Femtocell downtown coverage range [m]	NPV [mill. €]
10,0	-1,3
20,0	0,4
30,0	2,2
40,0	3,4
50,0	4,0
60,0	4,3
70,0	4,5
80,0	4,6
90,0	4,6
100,0	4,6
110,0	4,6
120,0	4,6

Table 30 Sensitivity to femtocell downtown coverage range.

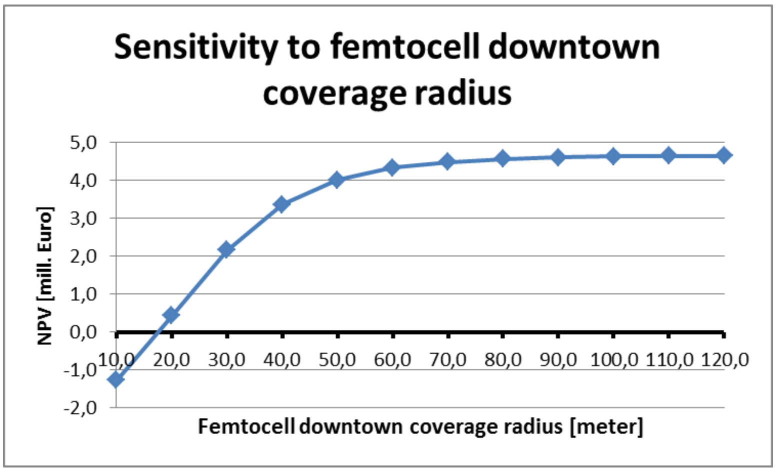

Figure 27 Sensitivity to femtocell downtown coverage range

The base case assumption is that the average femtocell downtown coverage radius is 75 meters. This value is based on well-established propagation models and good spectrum efficiency at the cell edge. It can be seen from Figure 27 that the profitability of the business case only gets significantly affected when the coverage radius gets less than about 50 meters and the NPV stays positive even for very small coverage ranges.

Hence it can be concluded that the profitability is only moderately sensitive to the femtocell downtown coverage radius.

5.4.2.9 Sensitivity to femtocell suburban coverage range

Table 31 and Figure 28 show the sensitivity to the femtocell suburban coverage range.

The base assumption was a coverage range of 90 meters which was based on well-established propagation models and good spectrum efficiency at cell edge. It can be seen that this coverage range has stronger impact on the NPV than the downtown coverage range. The NPV becomes negative for a coverage range of about 50 meters.

Even if this is not among the most critical parameters for the business case, the fixed operator should verify the validity of the base assumption before deciding to deploy such a system.

Femtocell suburban coverage range [m]	NPV [mill. €]
20,0	-10,1
40,0	-4,4
60,0	0,6
80,0	3,6
100,0	5,1
120,0	5,9
140,0	6,3
160,0	6,5
180,0	6,7
200,0	6,8

Table 31 Sensitivity to femtocell suburban coverage range.

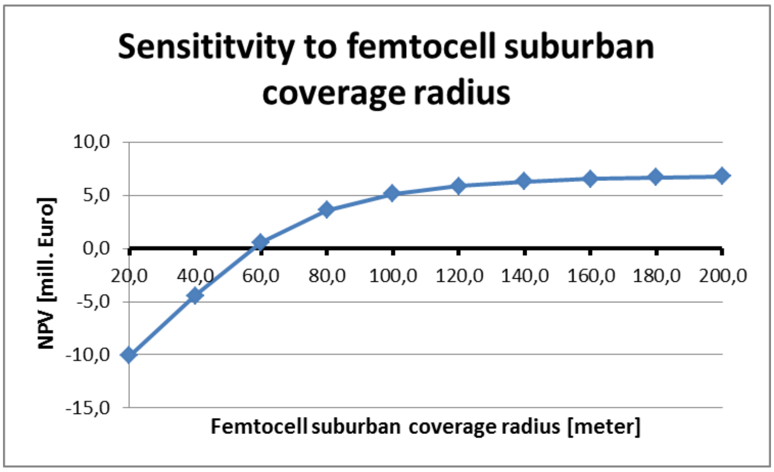

Figure 28 Sensitivity to femtocell suburban coverage range

5.5 Business case evaluation

This appears to be a promising business case. It is attractive for the subscriber since he or she gets a cognitive femtocell for free and a mobile broadband subscription which is cheaper than from a traditional mobile operator. For the fixed operator the investments the first years are moderate since the fixed infrastructure is already there and the main initial investments are for the mobile core components. The general OPEX will be high the first years, mainly due to high marketing expenses. Together this gives a moderate negative cash flow the first years. The accumulated cash flow is estimated to get positive after about 4 years. The NPV for the 5 year study period (2015 – 2020) is 4.5 million €.

But even if this business case is promising it should be realised that many of the assumptions are very uncertain and hence that no firm conclusions can be drawn. The results should be interpreted as only indicating that this is a possible business case.

The sensitivity analysis showed that the ARPU and the general OPEX were the most critical assumptions in the business case analysis. A very thorough analysis must be performed in order to get accurate estimates for these parameters before deciding on a cognitive femtocell deployment. The mobile service should give virtually the same user experience as traditional mobile broadband in order to get a sufficiently high ARPU. Also, the marketing needed during the first years should be as efficient as possible to avoid a too high general OPEX.

The cost of a cognitive femtocell is not among the most critical parameters, but still has notable influence on the business case profitability. Research and development work should focus on reducing its cost.

The average cognitive femtocell installation costs can also influence the business case profitability. Hence it is important that the Plug'n'Play functionality works properly so that assistance from a service engineer is only exceptionally needed.

The cognitive femtocell coverage range is of some importance in suburban areas, but of less importance in downtown areas where the density of femtocells will be high. It is important to determine what the coverage range will be in the area where a cognitive femtocell deployment is considered. It is also important to give the subscribers instructions on where to put the cognitive femtocell in order to get a good outdoor coverage.

The difference in the cost between a traditional LTE terminal and a cognitive LTE terminal is not expected to be a critical parameter. Also the spectrum database fee and the cost of the mobile core components have little effect on the business case profitability.

6 The "Machine-to-Machine (M2M) in whitespace" business case

There are many networks deployment options for a cognitive ad hoc network. What is common among these options is that there will be a high level of dynamics due to node mobility and QoS requirements. Recently one form of ad hoc network deployment has gained significant attention. This is machine-to-machine (M2M) networks. This is an ad hoc network in infrastructure mode. The "ad hoc" nature of M2M networks in this mode is that the terminals are portable and hence need to connect to the Internet (or owners fixed network) via any available base station. Overall there will be many devices with a range of QoS requirements meaning the network demands on each base station will be highly dynamic in both time and space.

6.1 Motivation

Machine-to-machine (M2M) networks are currently being given a lot of attention. A commonly quoted figure for the number of M2M devices worldwide is "more than 50 billion over the next decade" by Ericsson [Ericsson2011]. The range of connected devices is extremely diverse, including health care, utilities, transportation, smart devices to name a few. Ubiquitous connectivity will allow for these and other applications to develop over the next decade and beyond.

6.2 Business case description

This business case takes the point of view of an Operator deploying the infrastructure for an M2M network in the UK. This could be an existing network operator or a new entrant. As ubiquitous coverage is targeted to enable the growth of many of the potential M2M applications, TVWS are seen as a suitable frequency band due to the low cost and good propagation characteristics. This business case is based mainly on publicly available numbers. Many of the values extend on a brief business case highlighted by Neul [Egan2012].

6.3 Technical Considerations

6.3.1 Number of connected devices

For the UK there may be 50 – 100 million terminals. This can be realised based on the UK population's share of the 50 billion plus connected devices worldwide [Ericsson2011] or as stated in [Egan2012]. The base assumption for this work is that the uptake after saturation will reach 50 million terminals.

6.3.2 Coverage requirements

For a UK network with sufficient capacity for 50 million plus terminals around 5000 base stations would be required. In [Goodwins2011] it is said that between 4000 and 5000 bases stations are required for 99% UK population coverage. In [Webb2012] a capacity analysis is done for the UK with 6000 base stations. 5000 base stations are therefore used.

6.4 Assumptions

6.4.1 Phased roll-out and uptake

It is assumed that there will be a phased roll-out of the network infrastructure. The full deployment is expected by the end of year 4, with 35%, 75% and 95% deployment achieved by the end of year 1, 2 and 3 respectively. Once an area has infrastructure in place the uptake is expected to follow an s-curve which should reach 95% of the saturated number of customers for that area after approximately ten years. After 1 year and 7 years the uptake reaches 10% and 80% of the saturated number of customers respectively.

6.4.2 Average revenue per device

A single device could generate $6 per year [Egan2012]. This is equivalent to approximately £3.75 per year which is £0.31 per month. This value could vary depending on the connectivity requirements of the device and also on the margins for its own particular business case.

In [DECC2012] the combined benefits of smart metering in the UK; which includes reduced energy consumption, avoided site visits, reduced customer overheads and other savings; amounts to £15.8bn over a 20 year period. There are 50 million meters considered which equates to benefits of around £15.8 per year per meter. Per month this equates to a benefit of around £1.32 per meter. A company using smart meters, such as an energy provider, is one set of applications for an M2M network. The company would have many costs associated with smart metering, one of which would be the connectivity charges from the Operator. This shows that a value of £0.31 would be reasonable, but also that the charge could easily sway higher or lower depending on the overall costs associated with smart metering. For smart metering $10 per smart meter is a suggested annual subscription in [Webb2012]. In GBP this is approximately £6.25 per year which is around £0.52 per month.

6.4.3 Cost of CPE

This business case looks at the Operator providing the infrastructure for a customer to connect their devices. The cost of the CPE and its maintenance is therefore not a cost of the operator. The cost of CPE could affect how much certain M2M applications can pay for connectivity. We estimate that most devices can be produced with additional QoSMOS M2M functionality for less than an additional £10.

6.4.4 Cost of site rental and backhaul

It is intended to use existing locations for base stations in order to minimise costs. An existing location is a site where an antenna and base station can be installed or fitted which already has the required power and backhaul capabilities. For a single base station location it is assumed that the CAPEX for site rental (antenna installation, rack for base station, power, cooling, service charges etc.) and backhaul is £10k. The annual OPEX for a single site is assumed to be £2k with backhaul at £10k.

6.4.5 Cost of base station

It is assumed that a QoSMOS capable base station for M2M connectivity would cost approximately £10k. This gives a total CAPEX per site of £20k.

6.4.6 Cost of Cognitive Core network

The core network costs reflect those used for the cellular extension business case. This has costs for the CM-SM and the adaptation layer. This has a CAPEX of 174k€ (£145k) and 34k€ (£28k).

6.4.7 Cost of OSS

The cost of OSS modifications is dependent on what extra features are required that the network operators OSS doesn't currently provide. If the service is simply routing traffic to an M2M customer's network then this should be relatively low. If the service involves processing of some of the M2M data before handing over processed results to the customer then the costs will be high. The balance between CAPEX and OPEX can also be switched. For example, by creating new OSS systems specifically for M2M systems, the CAPEX will be higher, but OPEX can be reduced. For this work we have assumed a CAPEX of £1m. The OSS OPEX, together with the core network maintenance, is assumed to total £100k annually.

6.4.8 Cost of Database

In the previous QoSMOS business cases it is assumed that there is a fee for each connected device of 5 € (equivalent to £4). For an M2M however, we are assuming a much higher number of connected devices per base station, each individually requiring much less bandwidth and generating much less revenue. In order for a database provider to raise similar revenue from M2M, and to encourage M2M usage, a much lower fee is required per device. For this work a fee of £0.05 per device is assumed.

6.5 Business case calculations

6.5.1 Base case results

Table 32 shows a summary of the values used for this example. The business case calculations are then summarized in

Table 33. As this business case requires a large capital investment and has tight margins, the NPV is considered over 10 years. Over shorter periods a poor NPV would be almost certain due to the high initial investment and tight margins. Over ten years, with a discount rate of 10%, this produces a NPV of 16.4 million €. Figure 29 shows the accumulated cash flow for this example. This shows that cash flow would decrease over the first few years. This would be a result of the CAPEX from the phased deployment added to the fact that uptake would gradually increase only once an area has coverage. From year 4, the cash flow would start to increase, becoming positive early in the ninth year.

Table 32 M2M key values summary

Name	Value
Number of base stations required	5000
ARPU	£0.31 (0.39€) per month = £3.72 (4.65€)
Annual discount rate	2%
Base station site rental/maintenance and backhaul	£10 000 (12 500€)
Geolocation database	£0.05 (0.06€) per device per year
Core/OSS maintenance	£100 000 (125 000€) per year
Base station + installation	£20 000 (25 000€)
QoSMOS core network fixed costs	£200 000 (250 000€)
OSS integration	£1m (1.25€)

Table 33 Summary of business case calculations

Value (million €)	year 1	2	3	4	5	6	7	8	9	10
Revenues	4	16	33	54	79	106	130	150	164	173
OPEX	22	47	60	63	64	64	65	65	65	65
EBITDA	-18	-32	-27	-9	15	41	66	85	99	107
CAPEX	45	50	25	6	0	0	0	0	0	0
Cash flow	-63	-82	-52	-16	15	41	66	85	99	107
Accumulated cash flow	-63	-145	-197	-213	-197	-156	-90	-5	94	201

Year	Accumulated cash flow [mill. €]
1	-63
2	-145
3	-197
4	-213
5	-197
6	-156
7	-90
8	-5
9	94
10	201

Table 34 Accumulated cash flow for M2M

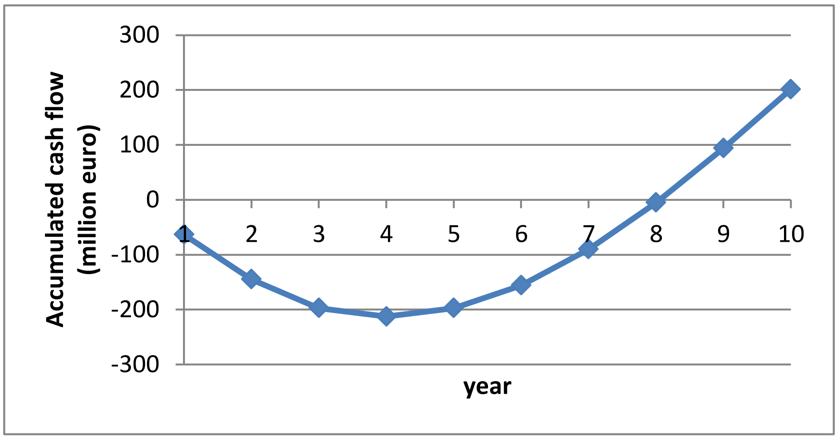

Figure 29 Accumulated cash flow for M2M

6.5.2 Sensitivity analysis

6.5.2.1 Sensitivity to number of devices

Figure 30 shows how the NPV changes with the number of connected devices. The base value was assumed as 50 million. If the number of connected devices is much less than this, the NPV would become negative. Conversely a much higher NPV would be forecast if there were more than 50 million connected devices.

Number of connected devices [10 million]	NPV [mill. €]
1	-383
2	-283
3	-183
4	-84
5	16
6	116
7	216
8	315

Table 35 Sensitivity to number of connected devices

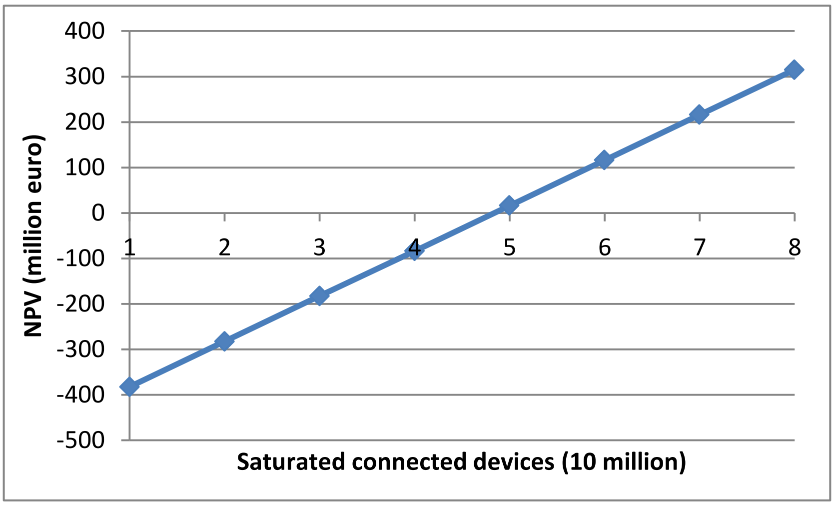

Figure 30 sensitivity to number of connected devices

6.5.2.2 Sensitivity to revenue per device

Figure 31 shows the sensitivity for this example with changing revenue per device. The base value was assumed as 0.39€ per month, which would produce a positive NPV. A decrease in revenue per device would cause the NPV to fall negative. For example, at 0.14€ per device per month the NPV would be below 300 million €. Higher revenues from the base value naturally lead to improved NPV values. For an NPV of 0.64€ the NPV would rise to over 300 million €.

Revenue per connected device [€]	NPV [mill. €]
0.14	-310
0.20	-229
0.26	-146
0.33	-65
0.39	16
0.45	98
0.51	180
0.58	261
0.64	342

Table 36 Sensitivity to revenue per connected device

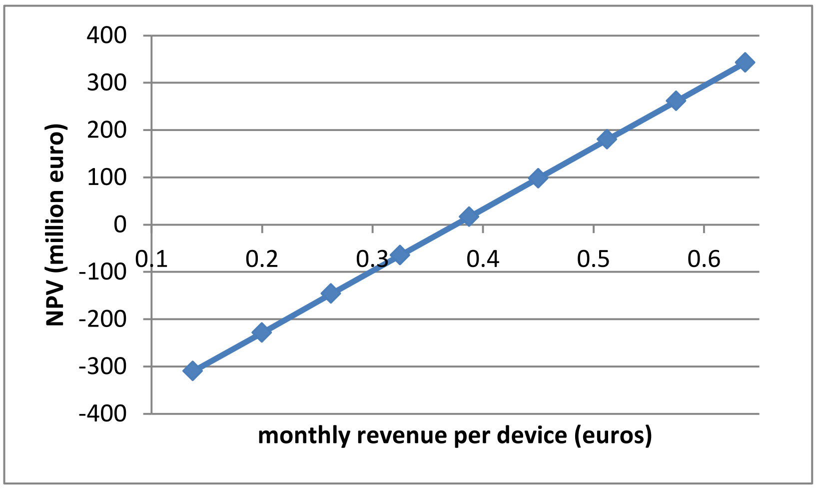

Figure 31 sensitivity to revenue generated per device

6.6 Business case evaluation

The business case model evaluated here shows that an Operator, after a large capital investment, would be able to make a profit within ten years. The base values assumed here show an NPV over ten years of 16.4 million €.

This business case has made assumptions about the scale of the M2M market that an Operator could service. There is much uncertainty about the base value assumed of 50 million connected devices. The sensitivity analysis has shown that this uncertainty could improve the NPV by hundreds of millions of Euros or make the NPV negative by hundreds of millions of Euros. The sensitivity analysis also revealed a similar level of change with the uncertainty in how much revenue can be generated per connected device.

The results clearly show the potential for an Operator to make a successful business. However, the risk is quite high if the number of connected devices or the revenue per connected device is overestimated.

7 Discussion and conclusions

Table 37 summarizes the main results for the business case studies. The base case NPVs vary from 3 to 115 million €, which does not reflect how relatively good the business cases are but rather the scale of the deployment considered. Since all the NPVs are positive when their base case assumptions are used, it can be concluded that all the considered business cases are potentially economic viable.

Table 37 Summary of the business case results

	OFFLOADING OF LTE NETWORKS	RURAL BROADBAND	COGNITIVE FEMTOCELL	COGNITIVE AD HOC NETWORK
Study period	2015 - 2020	2013 - 2023	2015 - 2020	2013 - 2023
Base case NPV	3.0 million € better than DD2 alternative	115 million €	5.5 million €	16.4 million €
Most critical parameters	Price of DD2 spectrum	Subscription fee and number of subscribers	Subscription fee and general OPEX costs	Number of M2M devices and revenue per connected device.
Most important QoSMOS related parameters	Cost of cognitive LTE terminal and cost of upgrading eNB.	Cost of CPE and installation.	Cost of cognitive femtocell, average femtocell installation costs and cognitive femtocell coverage range in suburban areas.	Database fee and cost of CPE
Risk	Moderate	High	Moderate	High

The subscription fee and number of subscribers (or equivalently the revenue per connected device and number of M2M devices in the cognitive ad hoc network case) are two of the most critical parameters in all business cases except the LTE offloading case. Hence it is very important to thoroughly investigate these parameters for the market in question before any investments are made. These parameters depend to a large degree on factors that are not related to the QoSMOS solution, but rather to external factors like the competition from other actors and the general economic climate. However, it also depends on the performance and quality of the service that can be provided by using the QoSMOS solution. Hence, it is important to focus on the QoSMOS system performance in future research and development work in order to ensure that it is possible to provide services that are at least as good and preferably better than what the customers can get using competing solutions.

Since the LTE offloading business case only compares costs between two alternative solutions (using TV white spaces or buying DD2 spectrum), costs and revenues that are common for the two options, like the subscription fee and number of subscribers, are not taken into consideration in the calculations. In this case it is the price of the DD2 spectrum that is the most critical parameter. However, this parameter is unrelated to the QoSMOS solution.

Regarding the most important QoSMOS related parameters, there is some variation between the business cases. The cost of the cognitive terminal is important in the LTE offloading case and the rural broadband case, but not in the cognitive femtocell case. The cost related to the cognitive base station is important in the LTE offloading case and the cognitive femtocell case. Installation costs are important in the rural broadband and the cognitive femtocell cases.

The risk or uncertainty also varies between the business cases. The LTE offloading and cognitive femtocell cases have moderate risk while the rural broadband and cognitive ad hoc network cases have high risk. This is also reflected in the study periods where the business cases with moderate risk have positive NPVs for a study period of 5 years while the high risk business cases give positive NPVs for a study period of 10 years.

It should also be noted that in all business cases the spectrum database fee turned out to be a non-critical parameter. Hence, this expense is not expected to affect the attractiveness of QoSMOS solutions, and hence their uptake in the market, significantly.

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Appendix 1: Techno-economic nomenclature and definitions

QoSMOS is an innovative concept and much research and development remains to be done before commercial applications will appear. Therefore the input data to the QoSMOS business cases is uncertain and the results from the business case calculations can only give indications, not yet definite answer or strong conclusions. The main value of QoSMOS business case calculations is to identify the critical aspects for QoSMOS profitability, so that the technical R&D work can focus on them.

The traditional cash flow analysis will be used to get an indication of the profitability. The cash flow means income (revenues) subtracted by cost (investments and operational costs) for a given time period. Due to large uncertainties the cash flow analysis must be enhanced with sensitivity analysis. Sensitivity analysis is done by changing the value of one (critical) input parameter and showing how the economic results are changing.

Several economic concepts are used in the business case analyses in this document. These are summarized below:

ARPU (Average Revenue Per User)

Average revenue per user (sometimes average revenue per unit) usually abbreviated to ARPU is defined as the total revenue divided by the number of subscribers.

CAPEX (Capital expenditures)

Expenditures associated with the implementation or extension of fixed assets. There is a residual value associated to these expenses. **Investment** is often used as an identical term to CAPEX.

OPEX (Operational expenditures)

OPEX is defined as expenditures necessary for running the business or the equipment, indispensable to keep the services active and running. Once made, these expenses have no residual value.

EBITDA (Earnings before interests, taxes, depreciation and amortization)

EBITDA = Revenues – OPEX. This measure is often used to estimate the operational efficiency..

NPV (Net present value)

NPV is the sum of a series of cash flows (revenues subtracted by costs), when discounted to the present value:

$$NPV = \sum_{t=1}^{n} \frac{A_t}{(1+p)^t}$$

where p is the annual discount rate, A_t the payment in year t and n the lifetime of the project. NPV is the most important criteria when defining the profitability of the project.

Discount rate

Discount rate is the rate used for discounting amounts to other points in time as in the calculation of NPV. It reflects the inflation and the fact that the estimated amounts in the future carry significant uncertainty. Typical values of discount rate are around 10%.

IRR (Internal rate of return)

IRR is the discount rate, that gives NPV = 0. The higher the IRR is, the better the project is. Assuming all other factors are equal among various projects, the project with the highest IRR would probably be considered the best.

Payback period

Payback period is the amounts of years that it takes to have the accumulated revenues equal the accumulated costs (CAPEX and OPEX).

These concepts are not necessarily always unambiguous; there can be slight variations and different interpretations. More information about economic terms can be found e.g. in [invest].

Appendix 2: Capacity of a cognitive LTE system

One of the most important parameters to consider in the cellular extension scenarios is the amount of extra capacity that cognitive radio can add to a cellular network, e.g. by using one vacant 8 MHz TV channel. A simulation study was performed to estimate this capacity.

The cognitive LTE transmission scheme

It is assumed that the cellular operator gets cognitive access to one 8 MHz TV channel, and that he use a system based on LTE to communicate in this channel. We assume that the FBMC/SMT modulation scheme presented in deliverable D4.2 is used.

However, a small modification to the FBMC/SMT scheme in D4.2 is required in order to make the scheme fit into a LTE context where transmission opportunities are allocated as Resource Blocks (RBs). In D4.2, the number of active carriers is 482. Unfortunately, the only prime numbers that divide 482 are 2 and 241 making it difficult to divide the carriers into RBs. To get a more appropriate subdivision in RBs, the number of carriers is reduced by 2 to 480 (= $2^5 \cdot 3 \cdot 5$). In this case the carriers can be grouped into 40 RBs, each having 12 subcarriers.

The frequency separation between carriers is 15 kHz, hence the total bandwidth of the signal is $480 \cdot 15$ kHz = 7.2 MHz and a RB is $12 \cdot 15$ kHz = 180 kHz wide (the same as for conventional LTE systems).

Simulation model

The SEAMCAT simulator [13] was used to estimate the achievable aggregate downlink and uplink bitrates for the cognitive LTE system. This is a tool provided by CEPT to estimate interference between networks. While primarily being a tool for evaluating interference scenarios, it also includes a module that can be used to estimate the capacity obtained in a LTE network.

The cognitive radio can be used to provide extra capacity in hot-spots or it can be used at all BS sites throughout the network to give a uniform increase in the offered capacity. Based on this, three different simulation scenarios were considered:

1. A single LTE BS with one omnidirectional sector
2. A single LTE BS with 3 sectors
3. An “infinite” network of LTE BSs, each having 3 sectors.

The network in the last scenario consisted of 19 identical hexagonal 3 sector cells, where the capacity was determined for one of the sectors of the centre cell. SEAMCAT uses a wrap-around technique to remove the network edge effects and thereby creates a model of an “infinite” network.

All sub-carriers were used in all sectors, i.e. the re-use factor was 1. It was assumed that all the UEs had unlimited data to send and that all Resource Blocks (RBs) were used at all times, which means that the network load was 100%.

In LTE UL, power control was applied to the active users so that the UE Tx power was adjusted with respect to the path loss to the BS it was connected to. A look up table was used to map throughput in terms of spectral efficiency (bps per Hz) with respect to calculated SNIR (= C/N+I) (dB) level. The tables were taken from the 3GPP TR36.942 document [TR 36.942]. The maximum spectrum efficiency was 4.4 bit/s/Hz in downlink and 2 bit/s/Hz in uplink, giving maximum bitrates of 31.68 Mbit/s and 14.4 Mbit/s respectively.

For every iteration the UEs were distributed randomly over the geographical area covered by the LTE network. Then, the path loss to all BSs in the network were calculated for each UE and put in a ranked list with the BS with the lowest path loss at the top.

Mobility and hysteresis of handover will have the effect of delaying handovers such that not all UEs will be connected to the optimum base station. This effect is taken into account in SEAMCAT by keeping only the BSs that are less than a handover margin below minimum path loss in the BS list. The BS which a UE is connected to is then chosen at random from this shortened list. A handover margin of 3 dB was used in the simulations.

The 3GPP antenna pattern from TR 36.942 [14] was used for the 3 sector cells and the antenna gain was assumed to be 6 dBi. The centre frequency was set to 630 MHz and the Hata propagation model for urban environments was used with a log-normal shadow fading of 10 dB. The wall penetrations loss was a random variable with a mean of 10 dB and a standard deviation of 5 dB. The UE and BS receiver noise figure was set to 6 dB. As explained in [8] the antenna solution in a small hand held terminal has to be an integral part of the terminal construction and will therefore be small when compared to the wavelength. Based on this, the UE antenna gain is assumed to be -7 dBi.

The LTE network is assumed to be located in an urban environment and consist of equally sized cells. The inter-site distance is assumed to be 750 meters, which is a typical number for urban deployments.

The cognitive LTE capacities were estimated both in scenarios with and without external interference. The external interference was assumed to be co-channel interference from DVB-T transmitters. The reference planning networks for study large service area Single Frequency Network (SFN) and the small service SFN for urban environment described in ECC Report 49 [ECCrep49] were used to model the interfering DVB-T network. It was assumed that the DVB-T network was planned for fixed and mobile reception. This gives significantly higher DVB-T transmitter powers than networks planned for fixed TV reception only and should therefore be considered as a conservative assumption with respect to estimating the achievable cognitive LTE capacities. In addition «interference limited» planning were assumed (in contrast to «noise limited» planning) resulting in the addition of a power margin of 3 dB to the DVB-T transmitter powers. Operation in band IV or V was assumed.

Achievable capacities with no external interference

Figure 32 shows the total bit rate as a function of the total site EIRP for indoor UEs. It can be seen that the internal interference in a multi-cell LTE network limits the site capacity to about 14.6 Mbit/s. The EIRP limits set by FCC for fixed devices (ref. table 1) are 36 dBm and 30 dBm, which correspond to a site capacity of 14.3 Mbit/s and 14.0 Mbit/s respectively. Since this is only marginally lower than the maximum achievable capacity, it can be concluded that these EIRP limits will not limit the site capacity in this kind of network.

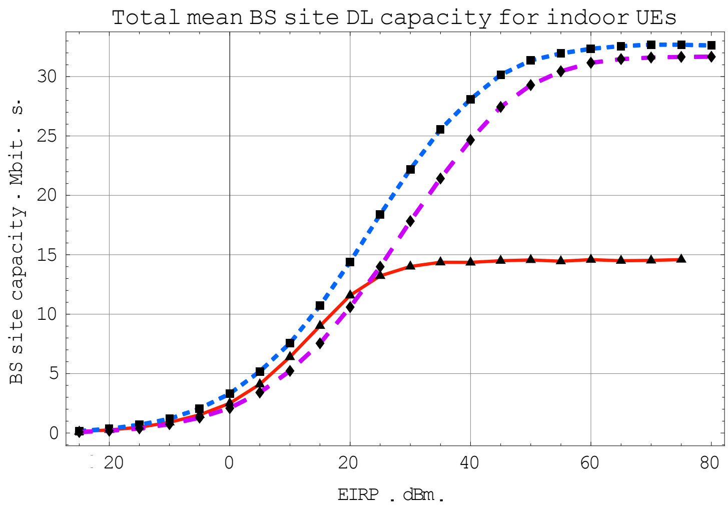

Figure 32 Total downlink site capacity for indoor UEs for single cell with 1 sector (diamonds), single cell with 3 sectors (squares) and an "infinite" network of 3 sector cells (triangles). The Inter-site distance is 750 meters and the LTE signal bandwidth is 7.2 MHz.

In the single cell (hot-spot) case the EIRP limits proposed by FCC and OFCOM will limit the capacity. For the single cell with 1 sector case, the site capacity is 22 Mbit/s for an EIRP of 36 dBm. The case of a single cell with 3 sectors has a site capacity of 26.1 Mbit/s for an EIRP of 36 dBm.

These calculations have been performed with the assumption that the UE antenna gain is -7 dBi which is expected to be realistic for a handheld user terminal. For terminals with larger form factors, such as laptops and tablets, larger antennas can be used and UE antennas gains approaching 0 dBi might be reached. For such terminals the margins in the infinite network case will be even higher.

In practice, there will be a mix of indoor and outdoor UEs and a mix of UEs with different form factors. Hence, the average capacities that will be achieved will be somewhat higher.

Figure 33 shows the uplink site capacity for the infinite LTE networks case as a function of the maximum UE transmit power. The gain of the BS antenna was set to 6 dBi. All UEs was assumed to be located indoor.

The maximum UE power when operating in a non-adjacent band is specified as 20 dBm by FCC and 17 dBm by OFCOM. This gives total site uplink capacities of 27.9 Mbit/s and 25.5 Mbit/s respectively, which is much higher than the achievable downlink capacities. For operation in adjacent bands, the maximum UE power is specified as 16 dBm and 4 dBm by FCC and OFCOM respectively. A maximum UE power of 16 dBm gives a site capacity of 24.5 Mbit/s, which also more than sufficient compared to the achievable downlink capacities. But a maximum UE power of 4 dBm, will give an uplink capacity of 7.3 Mbit/s, which is less than half the achievable downlink capacity. However, since many services require much lower uplink bitrates than downlink bitrates, even this uplink capacity should be sufficient in many realistic traffic scenarios.

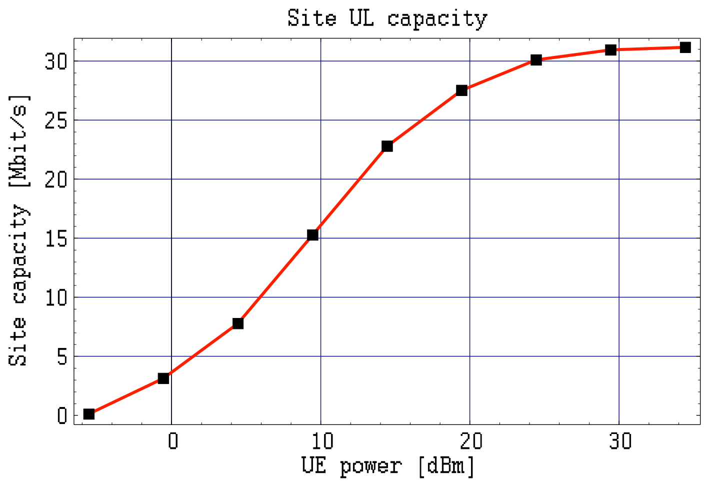

Figure 33 Total site uplink capacity as a function of the maximum transmitted UE power. All UEs are indoor.

Achievable capacities with external interference

Compared to an ordinary LTE network deployment, the cognitive LTE base stations transmit with significantly lower powers. The difference is not that large in the uplink. Standard LTE terminals transmit with 23 dBm, while cognitive LTE terminals are expected to use 17 – 20 dBm. However, in the downlink there is a huge difference. Conventional LTE base stations often have an EIRP of 60 dBm or more, which should be compared to only 36 dBm for cognitive LTE.

The simulations results for the case with no external interference showed that the much lower transmission power in the downlink did not reduce the capacity significantly for a LTE network. But the cognitive LTE network will be much more sensible to external interference than a conventional LTE network, and hence it is interesting to see how much interference from DVB-T transmitters will reduce the cognitive LTE capacity.

Figure 34 shows the DVB-T SFNs used to simulate external co-channel interference. In the large area SFN scenario each DVB-T SFN consists of seven identical transmitters located in the centre and the corners of a hexagon with an outer radius of 50 km. The SFN service area is given by a similar hexagon with 15% larger radius. In the small area SFN for urban areas scenario, each SFN consists of three transmitters placed in the corner of an equilateral triangle with sides equal to 25 km. However, the service area for the SFN is hexagonal.

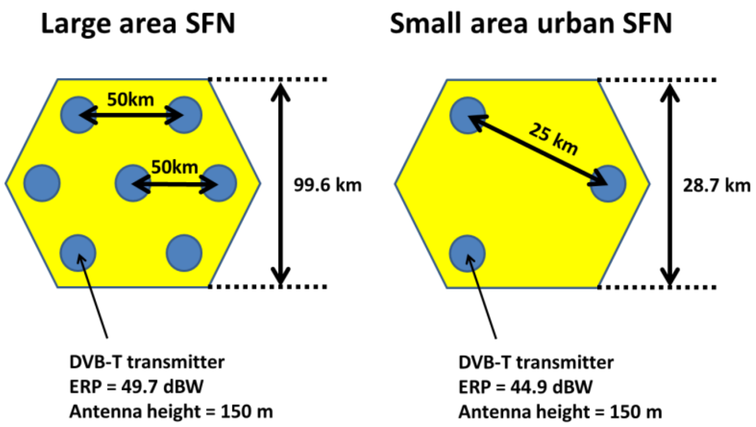

Figure 34 Reference networks for large service area SFN and small service area SFN for urban environment as given in ECC report 49.

The white space areas that the cognitive LTE network can use are located between the DVB-T SFNs as shown in Figure 35. In the simulations the LTE network was placed at different locations in the white space area and the sector capacity was estimated.

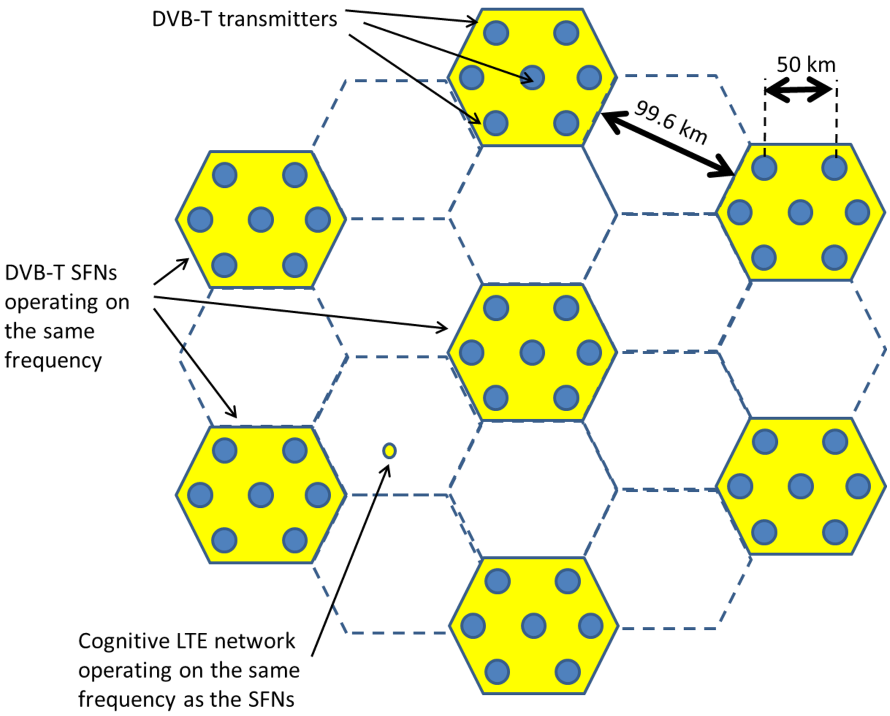

Figure 35 The cognitive LTE network is located in the white space areas between the DVB-T SFNs.

Figure 36 shows the results of the simulations for the large area SFN case, where high capacities are given as light colours ("whiter spaces") and low capacities with dark colours. The contours represent downlink site capacities between 0 and 13.5 Mbit/s in steps of 1.5 Mbit/s. As can be seen, there is a significant area where the site capacity is larger than 13 Mbit/s, which is only slightly lower than the

14.3 Mbit/s that was achieved in the external interference free case. However, the site capacity drops fast as the cognitive LTE networks closer to the DVB-T transmitters.

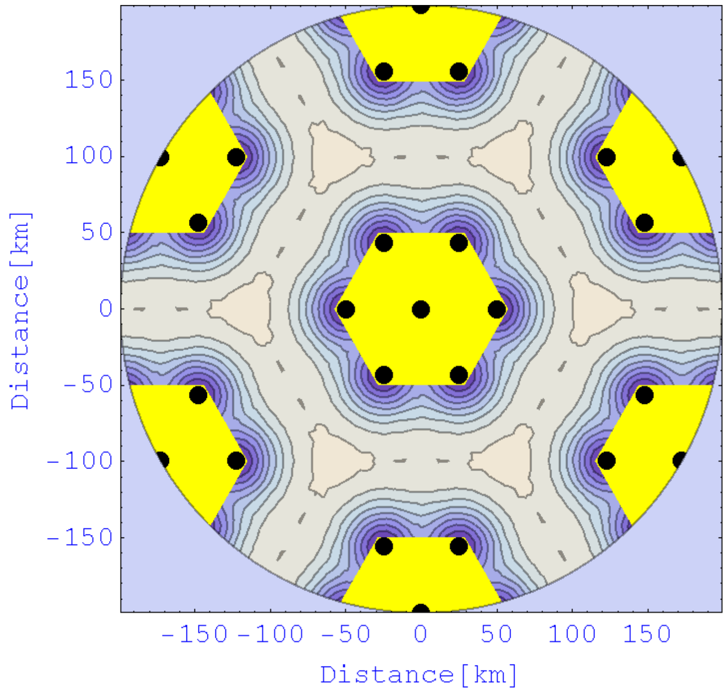

Figure 36 Downlink site capacity for a cognitive LTE network in TV white spaces in a large area DVB-T SFN scenario. Light areas represent high capacity and dark areas low capacity. The contours represent sector capacities of 0 to 13.5 Mbps in steps of 1.5 Mbit/s.

Figure 37 shows site capacity cumulative distribution function. It shows that 50% of the white space area has a site capacity larger than 11.7 Mbit/, and 90% of the area have a capacity larger than 5.7 Mbit/s.

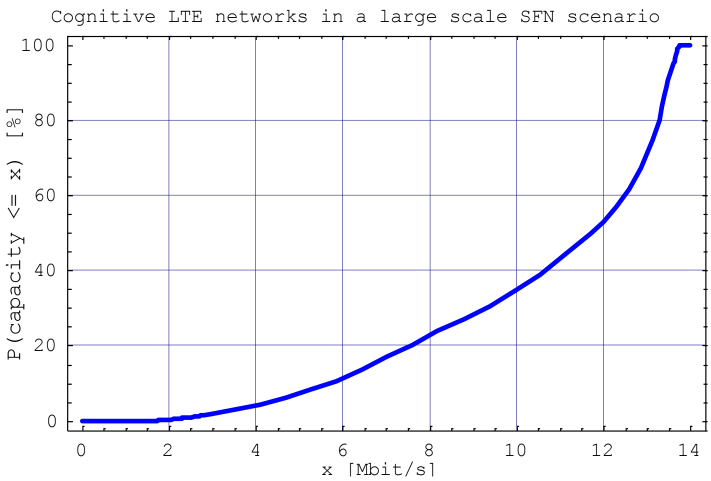

Figure 37 Downlink site capacity cumulative distribution function for the large area DVB-T SFN scenario.

Figure 38 shows the corresponding results for the downlink site capacity for the small area urban DVB-T SFN scenario. The contours represent sector capacities of 0 to 6 Mbit/s in steps of 0.5 Mbit/s. As can be seen, site capacities larger than 4.5 Mbit/s can be achieved in a large area. But this is significantly lower than the capacity achieved in the external interference free case.

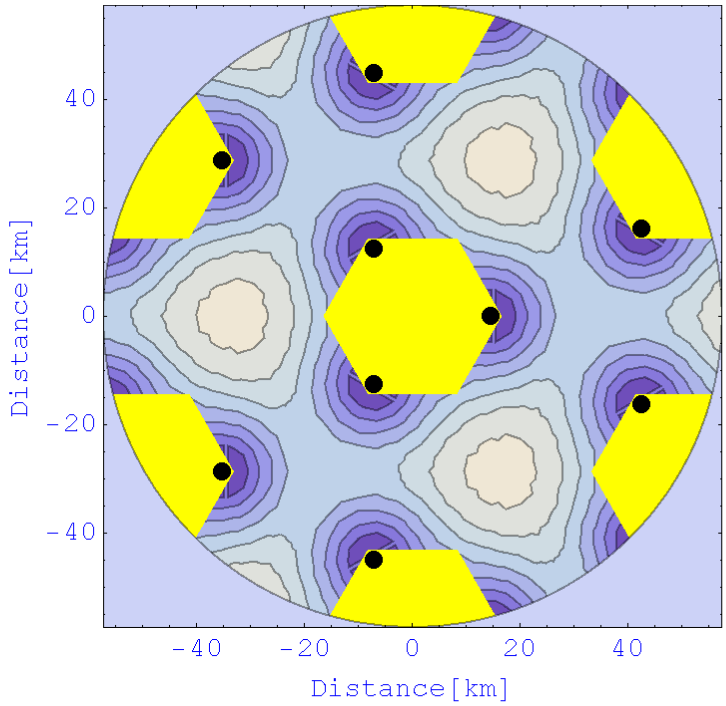

Figure 38 Downlink site capacity for a cognitive LTE network in TV white spaces in an urban DVB-T SFN scenario. The contours represent sector capacities of 0 to 6.0 Mbit/s in steps of 0.5 Mbit/s.

To see the effect of external interference on the performance of cognitive hot spots, this was simulated in the small area urban SFN scenario. The hotspot was modelled as a single cognitive LTE cell with three sectors. The results are shown in Figure 39 where the contours represent site capacities of 0 to 7.5 Mbit/s in steps of 0.5 Mbit/s. A site capacity of 5 Mbit/s can be achieved in a large area, but this is much lower than the 26.1 Mbit/s in the external interference free case.

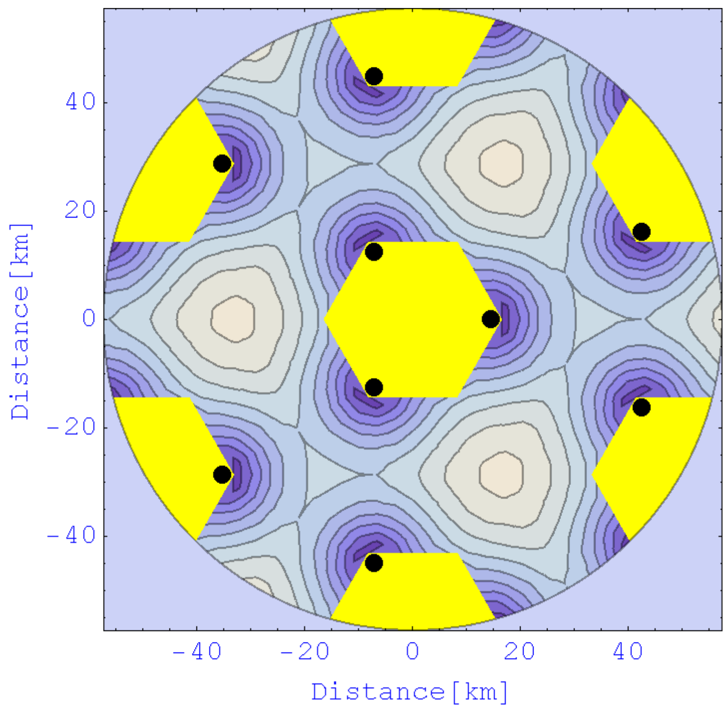

Figure 39 Downlink site capacity for a cognitive LTE hotspot cell with 3 sectors in TV white spaces in an urban DVB-T SFN scenario. The contours represent site capacities of 0 to 7.5 Mbit/s in steps of 0.5 Mbit/s.

Appendix 3: Coverage provided by randomly placed femtocells

The mean coverage of **n** randomly placed cognitive femtocells each with a coverage area **F** and coverage perimeter **L**, in a region with area $\mathbf{F_0}$ and perimeter $\mathbf{L_0}$ is [Laz06]:

$$Coverage = 1 - \left(\frac{2\pi F_0 + L_0 L}{2\pi (F_0 + F) + L_0 L} \right)^n$$

Indoor-to-outdoor communication with femtocells is modelled using the ITU-R P.1411 [P1411] recommendation on short range outdoor RLANs with a femtocell EIRP of 20 dBm (100 mW). For UHF propagation between terminals below roof-tops a combined LOS/NLOS model is given. It assumes a LOS area when the distance is short, followed by a transition region towards NLOS, which then models path loss for longer distances. The model assumes that antennas at both ends of the link are between 1.9 and 3.0 m above ground. The model also gives the possibility of calculating path loss for different percentage locations, however in this report only the median value is given (p=50%). The path loss in the LOS region is modelled as free space:

$$L_{LoS}^{median}(d) = 32.45 + 20 \lg f + 20 \log(d/1000)$$

In the NLOS region a higher attenuation factor is assumed (α=4) and higher frequency dependence is assumed as well:

$$L_{NLoS}^{median}(d) = 9.5 + 45 \lg f + 40 \lg(d/1000) + L_{urban}$$

L_{urban} depends on the urban category and is 0 dB for suburban, 6.8 dB for urban and 2.3 dB for dense urban/high rise.

The transition region is dependent on the percentage location, p. It is calculated using the equation below:

$$d_{LoS}(p) = \begin{cases} 212\left[\lg(p/100)\right]^2 - 64 \lg(p/100) & \text{if } p < 45 \\ 79.2 - 70(p/100) & \text{otherwise} \end{cases}$$

For p=50% it starts at d_{LoS} = 44.2 m. The width is chosen within the recommended range to be w=30 m. In the transition region, the path loss is modelled by linear interpolation between the $L_{LoS}(d)$ and $L_{NLoS}(d+w)$.

The building penetration loss is set to 11 dB according to EBU recommendations for DVB-H indoor use [EBU].

Using this model results in range estimates for both outdoor and indoor-to-outdoor coverage shown in Table 38.

Table 38 Range for cognitive femtocells

Frequency	630 MHz
TX EIRP	20 dBm
Building penetration loss	11 dB
Maximum propagation path loss @ 8dB SNR	103 dB
Cell ranges for suburban:	
Suburban outdoor femtocell	155 m
Suburban indoor-to-outdoor femtocell	90 m
Cell ranges for urban:	
Urban outdoor femtocell	105 m
Urban indoor-to-outdoor femtocell	75 m

It should be noted that the model is quite sensitive in the transition region [d_{LoS}, $d_{LoS}+w$] which is between 44 and 74 m in this case. We see that the urban indoor-to-outdoor coverage is just beyond this. Sufficient coverage is likely to be achieved only when there are LOS conditions between the building in which the femtocell is placed and the user. An important assumption for these results is also that the indoor femtocell is positioned close to an outer wall for the outdoor coverage to reach these ranges. In that case, outdoor use should be feasible.

The femtocell coverage range was estimated so that a SNR of 8 dB, corresponding to a spectrum efficiency of 2.8 bit/s/Hz according to Shannon's capacity theorem, could be achieved with a probability of 50% at the cell edge. The gain of the built-in antenna of the handheld terminal was assumed to be -7 dBi, which is the dimensioning case recommended by DVB-H [ETSI377]. Ranges of 75 and 90 m for urban and suburban coverage are then used for the base case calculations.

Figure 40 shows the coverage as a function of the number of femtocells in the downtown and suburban areas.

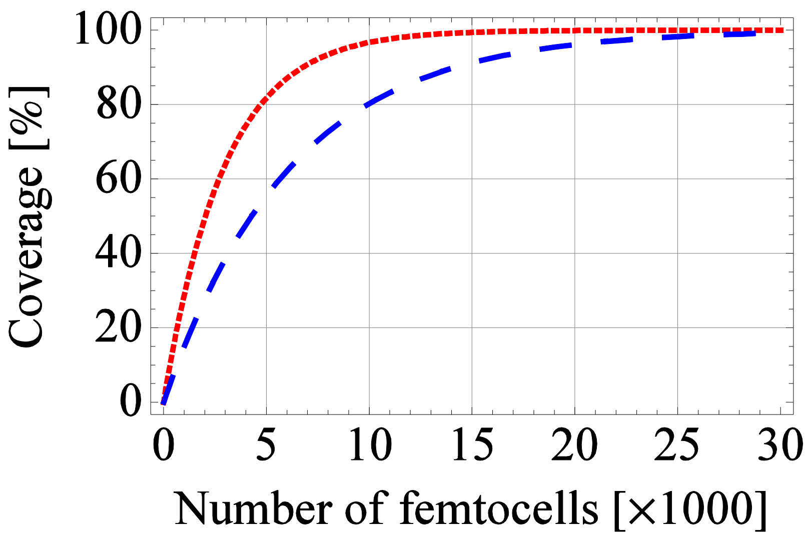

Figure 40 Coverage provided by randomly located femtocells in the city downtown area (small dashes) and the city suburban area (large dashes)

The figure shows that 99% coverage is achieved for about 13 500 femtocells in the downtown and 28 400 femtocells in the suburban area. 90% coverage is achieved by 6 750 femtocells in downtown and 14 200 femtocells in the suburban area.

The coverage curves are used in the business case calculations to estimate how much of the data traffic that goes over the cognitive femtocells, which is the traffic that the fixed operator will get revenue from.

It should be noted that as the number of cognitive femtocells increases, the probability that femtocells interfere with each other also increases. Hence, neighbouring femtocells need to coordinate their transmissions. Such methods are already specified by 3GPP as Inter-Cell Interference Coordination (ICIC) functions which are part of the Self-Organizing Networks (SON) framework, and even more efficient methods can probably be developed by targeting them specifically to control interference between cognitive femtocells.

Appendix 4: Estimation of roaming traffic

An important parameter in the femtocell business case is what percentage of the traffic that goes in other mobile operators' networks, since the fixed operator will not get any revenue from this traffic.

A subscriber of the fixed operator might be in one of three situations when he or she wants to use the mobile service:

- In his/her home or office. In this case the traffic will go in the fixed operator's own network. This will happen with a probability P_{home}.
- Outside his/her home or office at a location where there are no nearby cognitive femtocells belonging to other of the fixed operator's subscribers. In this case the traffic will go in another operator's network. This will happen with a probability P_{roam} (# femtos), which will be reduced as the number of femto-cells increases.
- Outside his/her home or office at a location where there are one or more nearby cognitive femto-cells belonging to some other of the fixed operator's subscribers. In this case the traffic will go in the fixed operator's own network. This will happen with a probability P_{friend} (# femtos), which will increase as the number of femto-cells increases.

Since these situations are mutually exclusive and covers all possibilities considered, $P_{home} + P_{roam} + P_{friend} = 1$.

The probability of roaming will be used as an estimate for how large part of the traffic that will be carried by other operators' networks. By this it is assumed that a cognitive femto-cell will always have sufficient capacity to serve all of the fixed operator's users that are within the coverage area of that femto-cell.

The parameter P_{friend} (# femtos) is estimated in the following way:

1. A subscriber which is outside of his/her office wanting to use the mobile service is assumed to be located in the city downtown area with a probability P_{userDT} and in the suburban area with a probability $P_{userSUB} = 1 – P_{userDT}$. The subscriber can be located anywhere in the downtown or suburban area with uniform area probability.
2. A new femto will be placed in the city downtown area with a probability $P_{femtoDT}$ and in the suburban area with a probability $P_{femtoSUB} = 1 – P_{femtoDT}$. The subscriber can be located anywhere in the downtown or suburban area with uniform area probability. The coverage radius of a femto is R_{DT} and R_{SUB} in the downtown and suburban area respectively.
3. The probability $P_{friendDT}$ that a subscriber being in the city downtown will be in the coverage area of at least one of the fixed operator's femtos is estimated as the ratio between the area covered by femtos located in the downtown area and the total area of the downtown area. $P_{friendSUB}$ is the corresponding probability for the suburban area.
   Then $P_{friend} = P_{friendDT} \cdot P_{userDT} + P_{friendSUB} \cdot P_{userSUB}$.

The part of the traffic that will be roaming traffic is then given by:

$$P_{Roam} = 1 - P_{Home} - P_{friend}$$