QUASAR Deliverable D1.3

# Business Impact Assessment


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|---|---|
| Project Number: | INFSO-ICT-248303 |
| Project Title: | Quantitative Assessment of Secondary Spectrum Access – QUASAR |
| Document Type: | PU |

| | |
|---|---|
| Document Number: | ICT-248303/QUASAR/WP1/D1.3/120630 |
| Contractual Date of Delivery: | 30.06.2012 |
| Actual Date of Delivery: | 30.06.2012 |
| Editors: | Jan Markendahl (KTH), Seong-Lyun Kim (Yonsei Univ) |
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| Work package: | WP1 |
| Estimated Person Months: | 55 MM |
| Security: | PU[1] |
| Nature: | Report |
| Version: | 1.0 |
| Total Number of Pages: | 90 |
| File: | QUASAR_D1.3_120630 |



## Abstract

This report includes findings on the business feasibility of wireless services provided by use of secondary spectrum access. The focus in the report is on three different scenarios describing *Cellular use of TV white space, Fixed operator use of TV white space* and *Cognitive machine-to-machine services cellular bands*.



## Keywords List

Secondary Spectrum Access, Business Models, Cellular, Machine-to-Machine, Secondary Spectrum Auctions, TV White Spaces


[1] Dissemination level codes: **PU** = Public
**PP** = Restricted to other programme participants (including the Commission Services)
**RE** = Restricted to a group specified by the consortium (including the Commission Services)
**CO** = Confidential, only for members of the consortium (including the Commission Services)

# Executive Summary

This report provides findings on the business feasibility of services based of secondary access of spectrum. The analysis focuses on two of the QUASAR service scenarios *Cellular use of TV white space (TVWS)* and *Cognitive machine-to-machine scenarios using cellular bands*. For indoor access services we also discuss the scenarios *Secondary spectrum commons in radar band* and *Indoor broadband using aeronautical band.*

One main finding from this analysis is the need to consider many aspects and scenarios. The results depend heavily on the working assumptions and the perspective of the analysis. It turns out that the QUASAR service scenarios cannot be seen as one specific scenario with well-defined properties. The techno-economic business feasibility depends on a number of aspects. Hence, each service scenario can consist of multiple sub-scenarios. The analysis shows that the business feasibility depends on what kind of actor that provides the service and the amount of company assets and resources that exist (i.e. that can be re-used) or need to be acquired (i.e. require investments).

New actors that will use TVWS as the only resources will have much higher costs than an existing mobile operator since they have to invest in new infrastructure. The situation is even worse if they need to build up a customer base, customer care and billing platforms.

For fixed line operators there are good business cases based on TVWS when existing infrastructure like transmission, equipment rooms, power supply, etc. can be re-used. The BT analysis of the case in the UK is a good example.

Existing mobile operators with licensed spectrum and already deployed networks can use TVWS and cognitive radio (CR) as an alternative to deployment of new base station sites when capacity upgrades are needed. Although CR equipment has different cost-capacity characteristics than commercial LTE solutions, the addition of CR to exiting sites may still be more cost efficient than deployment of new sites using licensed spectrum.

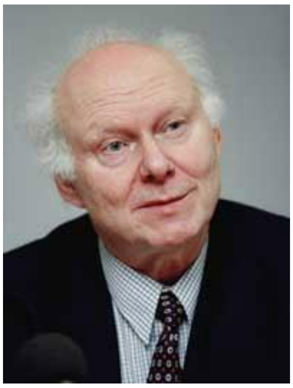
For existing mobile operators allocation of more licensed spectrum is in most cases more beneficial than use of TVWS for provisioning of mobile broadband services. Based on estimated availability and usefulness of TVWS channels in Germany it is found that it would be better for mobile operators if regulators were to go for a second digital dividend rather than allowing use of TVWS opportunities.

For indoor systems secondary access of spectrum can be used as a replacement or a complement to licensed and unlicensed operation. The business feasibility depends both on what type of business cases (offloading to mobile operators, roaming between operators or hot spot services offered to end-users) and on what actors that provides the service. Again it is the amount of resources that need to be acquired (i.e. costs) that are different for different types of services and the actor that provide the service.

Existing mobile operators with licensed spectrum can use TVWS as additional resources to provide M2M services. There is a potential to use TVWS without incurring excessive cost for building new base station sites. New actors for providing infrastructure based M2M services are hard to succeed in the CR business with TVWS. New actors do not have any infrastructures for their services; hence they need to invest in building new base station sites for M2M services which incur large costs rendering the business case less valuable. By leasing the infrastructure from existing mobile operators, new actors can provide M2M services in the type of MVNO.  Agreements with legacy operators need to be set up to allow this type of sharing. However, M2M services in TVWS still have challenges for the following reasons: The TVWS ecosystem is immature. The regulation is at an early stage and geo-location databases for TVWS are only available in the USA. Some network equipment, chipsets, and devices for TVWS applications are in development, but few solutions have been announced so far.

The report also includes as short description of spectrum access options together with a description and analysis of different auction mechanisms where spectrum auctions with whitespace-augmented spectrum pools are compared.

**Dedication:** We dedicate this deliverable to the memory of our esteemed and dear colleague at KTH and QUASAR collaborator Östen Mäkitalo, the father of Nordic Mobile Telephone. He contributed with great interest and enthusiasm to the initial version of this deliverable, kindly offering his advice and vast experience to the project as a whole and the work in WP1.



Östen Mäkitalo 27 August 1938 – 16 June 2011

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# 1 Introduction

In this report we present findings on the business feasibility of mobile services provided by use of secondary spectrum access. The focus in the report is on two of the QUASAR service scenarios called *Cellular use of TV white space* and *Cognitive machine-to-machine scenarios using cellular bands*. For service provisioning in indoor locations the following scenarios are relevant: *WiFi-like use of White Spaces, Secondary spectrum commons in Radar band* and *Indoor Broadband using Aeronautical band.*

We would already in the introduction highlight the fact that each of the QUASAR service scenarios not can be seen as one specific scenario with well-defined properties. The techno-economic business feasibility depends on a number of aspects. Hence, each service scenario can consist of multiple sub-scenarios. The business feasibility is not an inherent property of any type secondary use or the type of primary spectrum; instead the business feasibility depends on specific business cases. Hence, we will look into a number of different sub-scenarios characterized by:

- The availability of spectrum for secondary use
- The type of service intended for secondary use
- The demand and willingness to pay for the service
- The type of radio access technology used for the specific service
- The cost structure for network deployment options
- The cost for spectrum licenses
- If the secondary use of spectrum is intended as complement to an existing service or if it will be the basis and only resource for the service
- The characteristics of the actor providing the service

In addition, it is very important to look into the business cases of competing solutions. It may very well be that there is a lot of spectrum available for secondary use and that the cognitive radio (CR) technology will work. However, if competing solutions have better performance in the business domain, the solutions based on use of secondary use of spectrum will not be able to take off.

Another key factor in the analysis is to consider the type of actor that provides the service and the kind of resources and capabilities the actor has – or do not have. For the analysis of *Cellular use of TV white space* we consider existing mobile operators, fixed line operators and new operators using TVWS only. The analysis of this scenario is done using three different analysis perspectives, presented in different chapters. For the analysis of the service scenario *WiFi-like Use of White Spaces* we also include Mobile Virtual Network Operators (MVNOs), WiFi operators and facility owners that provide services. For the service scenario *Cognitive machine-to-machine scenarios using cellular bands* we consider CR operators leasing network capacity.

The report is outlined as follows. In chapter 2 we summarize general aspects of the so called "spectrum opportunity" used for the business impact assessment. In chapters 3 – 5 we present business feasibility results for TV white space scenarios using different perspectives and chapter 6 includes a business analysis of a cognitive M2M communication scenario. Chapter 3 includes analysis from a demand, cost and resource perspective, chapter 4 analyses TV WS from the perspective of a fixed line operator and chapter 5 presents a cost-revenue analysis from the perspective of an existing mobile operator. In chapter 7 we spectrum access options are discussed and the mechanisms using spectrum auctions with whitespace-augmented spectrum pools are analysed. Finally, chapter 8 contains conclusions and implications for further analysis.

# 2 Business opportunities of secondary spectrum access

## 2.1 The QUASAR Services Scenarios

EU FP7 QUASAR project[2] develops the promising scenarios of secondary spectrum access: Cellular use of white spaces, WiFi-like use of white spaces, secondary wireless backhaul, secondary spectrum commons in radar band [TSZ11], indoor broadband in aeronautical spectrum [SOZ11-1; SOZ11-2] and cognitive M2M communication. Brief description of each scenario is addressed as follows [KNSZK10].

In *cellular use of white spaces* scenario, a cellular system is the secondary system of TV white spaces. The cellular system can enhance its throughput or extend its coverage. This scenario also includes the case of a fixed-line operator who wishes to deploy long-range wireless communication services in *white spaces*.

In *WiFi-like use of white spaces* scenario, the secondary system is WLAN-like service provider. By using TV white spaces, the secondary system can provide high data rates to nomadic secondary users.

In the *secondary wireless backhaul* scenario, wireless backhauling and relaying are assumed to be secondary systems. The candidates of primary spectrum for this scenario are TV white spaces and radar bands. The scenario could be the solution of the capacity provision of backhaul.

In *secondary spectrum commons in radar band* scenario, the radar band is suggested as a primary band for secondary spectrum access. The technical obstacles and economic practicality of spectrum common access to radar band are addressed.

In the *indoor broadband in aeronautical spectrum* scenario, the viability of secondary access to aeronautical spectrum is investigated. The candidate primary spectrum is the aeronautical navigation band (960-1215 MHz). The secondary system is assumed to be a mobile broadband system that provides indoor coverage.

In *cognitive M2M* scenario, infrastructure or ad hoc M2M communication is performed in secondary spectrum. This includes local area communication for smart grids and sensor networks.

Table 2-1 shows primary spectrum, secondary system, secondary usage type, spectrum sharing type and licensing type of the scenarios based on the QUASAR document D1.1 "Models, Scenarios, Sharing Schemes".

Table 2-1: Comparison of QUASAR Scenarios.

| | *Primary Spectrum* | *Secondary System* | *Secondary Usage Type* | *Spectrum Sharing Type* | *Licensing Type* |
|---|---|---|---|---|---|
| *Cellular Use of White Spaces* | TV broadcasting Band | Cellular communication System | Wide area or indoor | Interweave [1] | Secondary exclusive or secondary sharing license |
| *WiFi-like Use of White Spaces* | TV broadcasting Band | WLAN-like service Provider | Wide area or indoor | Interweave | Secondary sharing license or secondary spectrum commons |

[2] EU FP7 QUASAR Project, http://www.quasarspectrum.eu/

| | | | | | |
|---|---|---|---|---|---|
| *Secondary Wireless Backhaul* | TV broadcasting band or radar band | Point-to-point communication system using directional antenna | Backhaul | Interweave | Secondary exclusive or sharing license |
| *Secondary Spectrum Commons in Radar Band* | Radar band | Wireless system similar to WLAN operation | Wide area or indoor | Interweave | Secondary spectrum commons |
| *Indoor Broadband in Aeronautical Spectrum* | Aeronautical navigation band (960-1215 MHz) | Mobile broadband system | Indoor | Interweave | Secondary sharing license |
| *Cognitive Machine-to-Machine (infrastructed)* | Cellular band | Machine-to-machine communication system | Outdoor | Interweave or underlay [2] | Secondary sharing license |
| *Cognitive Machine-to-Machine (ad hoc)* | TV broadcasting band but not limited to them | Machine-to-machine communication system | Indoor or microenvironment | Underlay | Secondary spectrum commons |

[1] Secondary users transmit packets using frequency holes that are not in use by the primary users.
[2] Since the secondary usage of the spectrum is very short and bursty, the secondary packets are transmitted with sufficiently low power not to degrade the primary system performance.

## 2.2 **Business opportunity analysis**

The basic operating mechanism of CR is allowing the primary users to share their spectrum with the secondary users. Radio spectrum, however, is usually regulated by some authorities because it belongs to the public property. Therefore, we can learn some lessons from the industry dealing with those kinds of public property, such as airline, railway, and utility industry, etc.

Let us consider the airline industry with the relation between the legacy (LC) and low cost (LCC) carriers. In the airline industry, the resources are time slots (in time domain) for departure and arrival in a given airport, and the airport itself (in the space domain) used by the airline operators. The primary operators (LC) can make sublicense with the secondary (LCC) for using the time slots or airports that are not well used by the LC. Remember that all the LCCs have a strict plan to use the unpopular slots (e.g., very early or lately) or airport remotely located by the city centers. The ownerships of the resources are well defined by the airline regulatory bodies and the some exclusive licenses are given to the secondary LCC operators. The key success factor of the secondary operators is in the low cost service, and the main service domains are intra-continental flights. This is differentiated by the service area of the primary LC, where the most of their targets are for the inter-continental business trips. In the airline industry, the profits and the market share of LCC has been increasing continuously and the now the primary LC are seriously looking at the business models of the LCC. Today, there are some LC operators that spin off its sister LCC operators, and making code share between them.

The same analogy can be applied to secondary spectrum access. From the point of view of this sharing structure, there are three basic factors that determine the business opportunities of CR services, which are 1) spectrum license ownership by the primary, 2) spectrum license ownership by the secondary, and 3) service differentiation between the primary and the secondary.

The spectrum license ownership means the level of exclusiveness in the spectrum license of interest. The more exclusive the primary spectrum license ownership is, the more freely the primary license holder can manage the spectrum (e.g. leasing or sharing it). For the spectrum of primary users, it can be traded in a free market or adjusted by particular regulators, or its trading can be prohibited according to the license ownership. If it is clear who has the license of the primary spectrum, any secondary operators can contact with the primary spectrum license holders to lease or get sublicenses of that spectrum. This implies that the primary spectrum has more business opportunity.

The spectrum license ownership by the secondary also affects the opportunities of CR business. Imagine the secondary access rights are open to anyone and the spectrum is shared, then it is hard to control the quality of services (QoS), provided by the multiple secondary operators. If the licenses are exclusively given to some secondary operators, however, the secondary operators can guarantee the minimum QoS level for maintaining the target services.

With these spectrum ownerships, the service differentiation between the primary and the secondary is important as well. In case that there are much overlap between the primary and the secondary service areas, the primary license owner is reluctant to lease the spectrum for the similar competing services by the secondary operators, most of which are with cheaper prices. On the other hand, if there is clear separation on the target services and customer groups between the primary and the secondary, both the primary and the secondary can get a mutual benefit from their spectrum sharing.

Based on those three factors, we can draw a cubic diagram which assesses the business opportunities of a CR service scenario. This diagram is valid for all types of secondary licensing, because the secondary licensing type is also reflected in the axis of secondary license ownership. The business opportunities of a CR service scenario may be maximized when the primary- and the secondary license ownerships are high with a great difference between their services (see Figure 2-1).

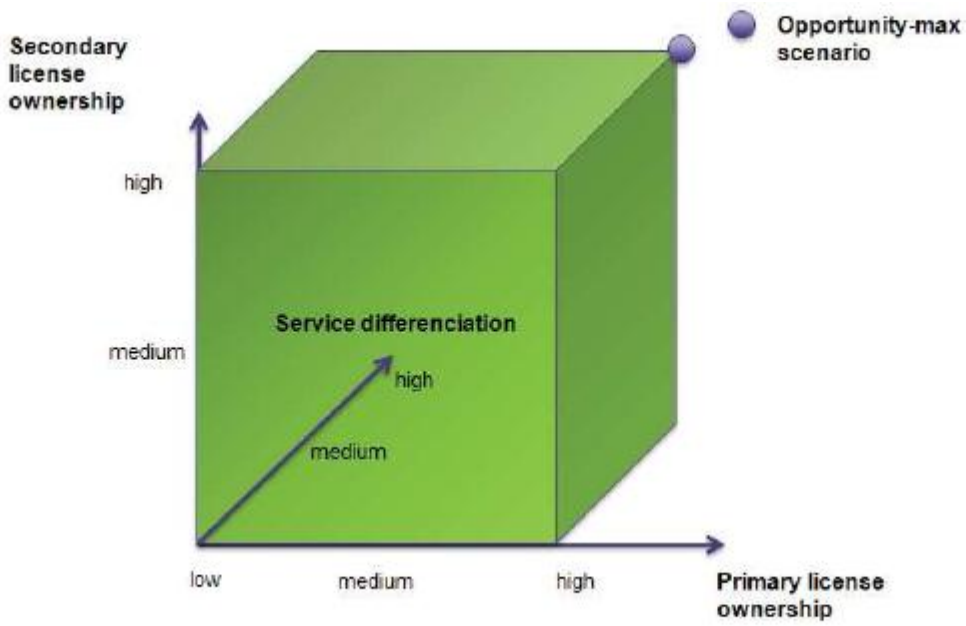



Figure 2-1: Ideal scenario for business opportunity.

Also for the scenarios presented in Table 2-1, the business opportunity of each scenario can be estimated using these three factors. Table 2-2 shows that and each element in the table is based on the primary spectrum bands, secondary usage type and spectrum sharing type in Table 2-1.

In the case that the primary spectrum is TVWS, it is unclear who has the right to use the broadcasting spectrum band in many countries. Mostly, TV towers are allowed (licensed) to broadcast signals using the designated frequency spectrum, whereas neither broadcasting company nor TV Tower Company has any rights to own or lease the spectrum. Therefore, the secondary operators do not know where to contact to borrow the spectrum for secondary access. In cognitive M2M scenario, on the other hands, the primary spectrum comes from cellular networks. Since the cellular operators have the full ownerships over the spectrum for cellular services, the spectrum can be easily leased or sublicensed with the permission by the regulators. This accelerates the sharing of the unused spectrum by the primary and the secondary.

For the service differentiation, it is important how the customer groups of the primary and secondary services are correlated temporarily and spatially as well as how both services are different from each other. When we utilize TVWS for cellular services, there are less spectrum holes in urban area than in rural area. The demand of cellular service, however, is higher in urban area similarly to that of TV broadcasting services. This lowers the business opportunity of secondary cellular services, even if the traffic pattern of cellular services is different from that of TV broadcasting. Also in the scenario "Cognitive M2M (infrastructure)", the target service areas of both services are overlapping in the sense that more M2M traffic is originated in urban area. In case of highly delay-tolerant M2M traffic, the level of service differentiation can increase by transmitting the data packets when the occupancy of cellular spectrum is low.

Thus, not only the cellular use of white spaces but also cognitive M2M (infrastructure) in the cellular band can be a good candidate for CR services, as shown in Table 2-1 and Table 2-2.

Table 2-2: Business Opportunity for CR Service Scenarios.

| | *Primary license ownership* | *Secondary license ownership* | *Service differentiation* |
|---|---|---|---|
| *Cellular use of white spaces* | Medium | High | medium |
| *WiFi-like use of white spaces* | Medium | Medium | medium |
| *Secondary wireless backhaul* | Low | High | high |
| *Secondary spectrum commons in radar band* | Low | quite low | High |
| *Indoor broadband in aeronautical Spectrum* | Low | Medium | High |
| *Cognitive M2M (infrastructured)* | High | Medium | medium |
| *Cognitive M2M (ad hoc)* | Medium | quite low | medium |

# 3 Business Analysis of Cellular use of TV White Spaces

In this chapter we present a business analysis of mobile broadband access services, i.e. one type of cellular use, using TV white space as the spectrum resource. The results are based on presentations at COST-TERRA June and November 2011 [Mäkmar][MGSM11] , on papers presented at the 22nd European regional conference of the International Telecommunication Society (ITS) 2011 [Marmäk11], the ITS India Conference 2012 [Marmöl12] and two papers presented at Crowncom 2012 [MarCas12] and [MGSM12]

## 3.1 Scope and objective of the analysis

The topic of this chapter is cellular use of TV white spaces where the service is mobile broadband access (MBBA). A number of business cases, representing different sub-scenarios of the QUASAR service scenario, will be analysed. We will look into MBBA services in rural and urban areas and for indoor use. The service can be provided by a mobile network operator (MNO) with licensed spectrum, by a virtual mobile network operator (MVNO) or a TV white space only operator (TVWSO), both without any licensed spectrum. We will also consider different types of local network operators, a WiFi hot spot operator and facility owners.

In this chapter we evaluate the business feasibility of services provided by different actors making use of secondary access of spectrum. In chapter 4 we consider the use of TVWS by a fixed line operator. In chapter 5 we compare cases where an existing cellular operator enhance the capacity by either using more licensed spectrum or by making use of secondary access of TVWS spectrum.

The strategies for how operators and other actors acquire spectrum are not described or analysed. We assume that the actors can use a certain bandwidth with some spectral efficiency depending on cell size and interference, see sections 0 and 0

Our starting point for the analysis is that the business viability is not an inherent property of the spectrum band or any type of secondary use of spectrum itself. The business viability depends on specific business cases including the intended service, the demand and usage, the type of deployment and cost structure of the network. We also need to consider the business cases of competing solutions. It may be that a technical solution based on cognitive radio works perfectly but that the resulting business case is outperformed in the business domain. Hence, we will analyse a number of sub scenarios where TV white space is used for MBBA. For each sub scenario we will analyze the impact of the following aspects:

- The type of service intended for secondary use
- The demand and willingness to pay for the service
- The characteristics of the actor providing the service
- The type of radio access technology used for the specific service
- The cost structure for network deployment options
- The cost for spectrum licenses
- If the secondary use of spectrum is intended as complement to an existing service or if it will be the basis and only resource for the service
- The techno-economic performance of competing solutions

We will show initial results in order to show what business cases look promising and should be analysed further. For these cases we focus on two research questions:

1. What kinds of business scenarios can be identified when a mobile operator makes use of TV white space spectrum for mobile broadband access services?
2. What business opportunities can be identified for these business scenarios?

## 3.2 **Analysis approach, models and assumptions**

### 3.2.1 General

The business analysis has shown that there is no general analysis approach that is applicable to all QUASAR service scenarios. Instead, the analysis is done using approaches that are tailor made to the specific sub scenarios and business cases. This is clearly illustrated for this service scenario with a multitude of different sub-scenarios, see section 3.2.2.

In our analysis we will focus on the potential business opportunities for services based on use of secondary spectrum. We will move away from doing the analysis starting with the technical design and the functionality, e.g. the use and implementation of geo-location data bases, spectrum sensing solutions, etc. We will do the business analysis assuming that all new technology will work as expected. The analysis will be done for a specific services making use of secondary spectrum in specific deployment scenarios by different types of actors. Hence, it is *not* the business opportunity of a specific technical solution, function or algorithm that is analyzed as a stand-alone feature.

In addition, the analysis is made on a high level using ideal conditions. This means e.g. a high availability of spectrum, technology that works as expected, an offered service with proven demand and paying users. If the analysis indicates that there are no viable business scenarios although these ideal conditions exist, then there is no need to make a more detailed analysis. On the other hand, the identified promising business cases are verified by a more refined analysis focused on the aspects that are most uncertain and/or has a big impact on the business performance.

### 3.2.2 A multitude of aspects leads to a multitude of business scenarios

As mentioned above there are a number of aspects that need to be considered for the business feasibility analysis. Hence, we cannot expect *one* single answer for each of the QUASAR service scenarios. For the analysis of "cellular use" of TV white spaces there are a multitude of factors and options to consider:

- The type of service, "cellular use" can mean many things, e.g. a mobile data access or voice service, data access combined with some special service or a M2M application.
- The type of radio access technology, the type of cognitive radio and geo-location data base and the approach for secondary use.
- The type of deployment area, in the case of mobile broadband access; rural, suburban, urban metro, or in hot spots and if consider indoor or outdoor users
- If the service is offered for public use, used within the own organization only (e.g. a forestry company), or if it sold as a wholesale offer to another actor that will provide the service to end-users
- What kind of actor offers the service; a mobile network operator (with licensed spectrum), a mobile operator without any licensed spectrum, (e.g. a TWSO), a broadcasting company that want to re-use "own" spectrum, a facility owner that offers local indoor access.
- The type of competing solutions, iis the service already available via some other network operating in frequencies other than TVWS?

Using the different combinations from the list above we could design a large number of sub scenarios composed by a number of business cases assuming different conditions. We consider use of TV WS by mobile network operators with licensed spectrum and by new actors called "TVWS only" operators (TVWSOs) and two types of usage; for mobile operators to complement capacity and for TVWS operators to obtain spectrum as the resource for its normal operation.

Within the service scenario "cellular use of TVWS" we will we consider the following sub-scenarios where different types of actors are making use of secondary access to spectrum.

- *Mobile broadband access in urban/rural areas provided by "TVWS only" operator* A new actor, a TVWSO (without any own licensed spectrum) will use own infrastructure and TVWS in order to offer MBBA services in urban/rural areas to consumers.
- *Mobile broadband access in urban/rural areas provided by a mobile operator* A mobile operator with allocated spectrum and existing sites will use TV WS as complement for capacity expansion in urban/rural areas
- *Indoor mobile broadband access provided by a "TVWS only" operator* A TVWSO (without any own licensed spectrum) will use TVWS in order to offer services to end-users and/or to offer "indoor capacity" to mobile operators
- *Indoor mobile broadband access provided by an existing mobile network operator* A mobile operator with licensed spectrum and a macrolayer network will use TVWS as complement for capacity expansion using indoor local networks
- *Indoor mobile broadband access provided by a local operator.* A local operator (e.g. a facility owner or a hot spot operator) will use TV WS and own indoor infrastructure in order to offer services to end-users and/or to offer "indoor capacity" to mobile operators

### 3.2.3 Modelling of demand

For dimensioning of mobile broadband access we define the user demand as the capacity needed per area unit expressed as Mbps per $km^{2.}$ This equals the average usage per user times the number of users per area unit. Mobile data usage is the amount of data sent and received per user during one month and usually expressed in GB.

For Europe the smartphone users typically consume 0,1 – 1 GB per month and laptop users with dongle consume 1 – 10 GB[3]. The usage needs to be expressed in terms of data rates. Assuming that the data is consumed during 8 hours per day all days a monthly demand of 10,8 GB corresponds to an average data rate of 0,1 Mbps. Hence, a monthly usage of 0,1 GB, 1 GB and 10 GB per month roughly corresponds to 1 kbps, 10 kbps and 100 kbps respectively [MMMW09] .

In order to estimate the demand per area unit we need to consider the population density and the penetration of the service offered by the provider. The orders of magnitude of the area demand are illustrated in table 3-1. The demand is shown for different "user" densities and for users with different demand levels. The dimensioning means that these numbers need to be matched by the offered capacity.

Table 3-1: Examples of required capacity as function of number of users and usage level.

| | | Area demand for different usage levels (Mbps /$km^{2)}$ | | |
|---|---|---|---|---|
| Geotype | Users per $km^2$ | 0,1 GB/month | 1 GB/month | 10 GB/month |
| Rural | 10 | 0,01 | 0,1 | 1,0 |
| Suburban | 100 | 0,1 | 1,0 | 10 |
| Urban | 1000 | 1 | 10 | 100 |
| Metro | 10000 | 10 | 100 | 1000 |

[3] http://www.pts.se/en-gb/Documents/Reports/Telephony/2011/Svensk-telemarknad---forsta-halvaret-2011---PTS-ER-201121/

### 3.2.4 Network and capacity model

*The radio access technology*

The "cellular use" of TV white spaces considered in all cases is mobile broadband access services. One motivation for this choice is the increasing demand for MBBA services and the relatively low amount of bandwidth that is currently allocated to mobile operators in the 800 MHz or 900 MHz band. Hence, additional bandwidth using TVWS would be a valuable resource that could be used to design new business cases. In the 800 and 900 MHz bands TVWS could be used as complement to or as replacement for licensed spectrum.

We assume that the MBBA service will be provided by a radio access technology like LTE with varying system bandwidth up to 20 MHz. We will compare the deployment of networks using the TV WS with deployment of MBBA using LTE in the 800 MHz band. In the analysis we consider cases with a relatively low number of available TV channels, 1-4 TV channels corresponding to a bandwidth of approximately 8 – 32 MHz.

*Offered capacity*

The offered capacity for the mobile broadband access service depends on the available bandwidth and the spectral efficiency. The offered cell capacity in Mbps equals bandwidth (MHz) * spectral efficiency (bps per Hz). The bandwidth depends on the number of TV channels available for secondary access, the spectral efficiency depends on the network deployment and interference from other secondary users. In our estimates we will use cell average values although we know that the spectral efficiency for MBBA depends on the location of the end-user. In Figure 3-1 the ITU spectral efficiency target data rates for LTE are shown for the peak, average and cell border values.

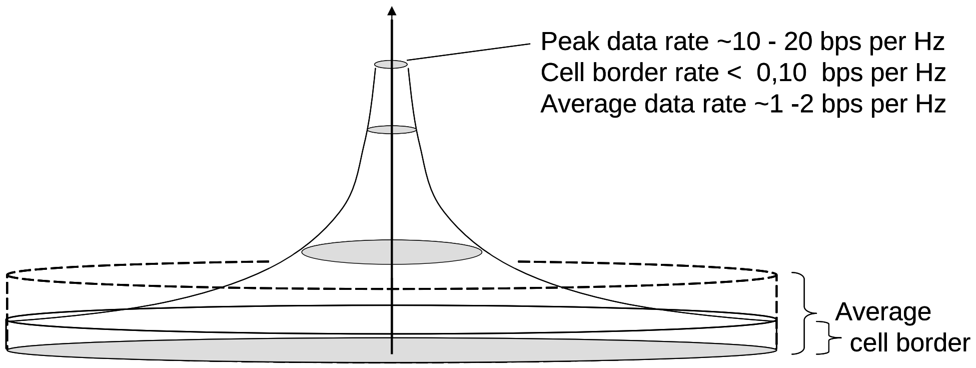



Figure 3-1: Spectral efficiency target values for LTE.

The orders of magnitude of the base station site capacity are illustrated using the examples in table 3-2, assuming a three-sector base station site.

Table 3-2: Examples of offered site capacity as function of bandwidth and spectral efficiency.

| Spectral efficiency | Bandwidth | Site capacity |
|---|---|---|
| 0,67 bps/Hz | 8 MHz | 16 Mbps |
| 0,67 bps/Hz | 16 MHz | 32 Mbps |
| 1,67 bps/Hz | 8 MHz | 40 Mbps |
| 1,67 bps/Hz | 16 MHz | 80 Mbps |

The estimated capacity for a base station site with three sectors is 3 * the spectral efficiency * and the bandwidth (3* SE * BW). Both the spectral efficiency and the bandwidth in terms of number of TV channels can vary according to Figure 3-2. With this model the key parameter is the product SE*BW with the dimension "bits per second". The parameter set {SE=1; BW=8} gives the same results as {SE=0,5 ; BW=16}, and {SE=0,25 ; BW=32}.

The impact of interference and different cell sizes can be reflected in the spectral efficiency. For deployment in urban and rural areas we typical values for spectral efficiency can be in the range 0,50 - 2,0 and 0,25 – 1,0 bps per Hz respectively. The lower spectral efficiency for deployment in rural areas combined with a larger bandwidth (due to more available TV channels) results in values of the product "SE*BW" in the same range as for urban deployment.

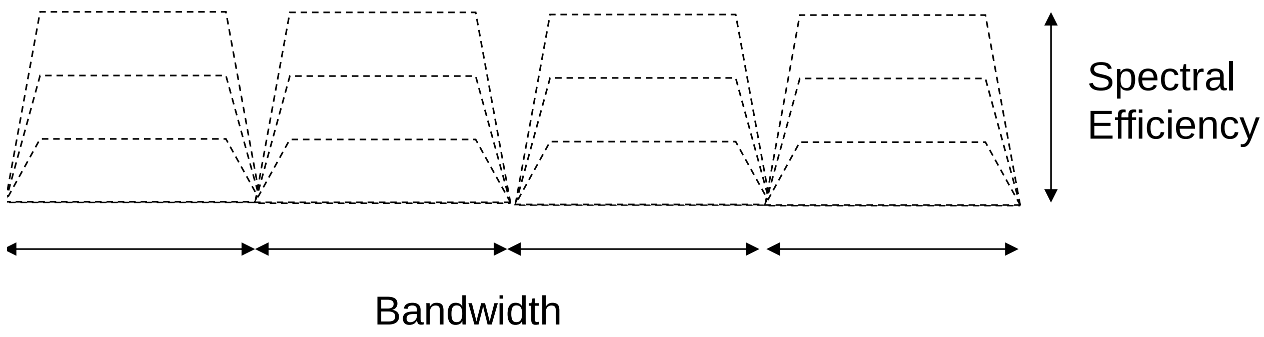



Figure 3-2: Bandwidth and spectral efficiency.

*Availability of TV white space spectrum*

In the QUASAR project the number of available TV channels has been estimated for a number of countries. The number of "un-used" TV channels is very low in most part the country, see Figure 3-3. "Many" TV channels are available in rural areas in northern Sweden, areas where the population density (and demand) is low. Please note that the availability of spectrum for secondary use depends on the type of services and the type of network deployment that is used. By using macro base stations with high towers the mobile broad band will cause interference over large distances, hence the spectrum availability is low. If the spectrum is used for indoor deployment using low power base stations then the secondary usage will cause interference in limited area and hence the number of "available" TV channels will be much larger.

For Sweden for cellular outdoor applications less than five channels are available in most parts of the country [D5.2]. Only in some rural areas in northern Sweden more than 20 channels are available, in these areas the demand is very low. One and four TV channels correspond to in total 8 and 32 MHz respectively. This can be compared with the spectrum allocation for the frequency bands intended for LTE in Sweden.

- At 800 MHz the operators have 10 MHz (downlink and uplink)
- At 2,6 GHz the operators have 10 – 20 MHz (downlink and uplink)

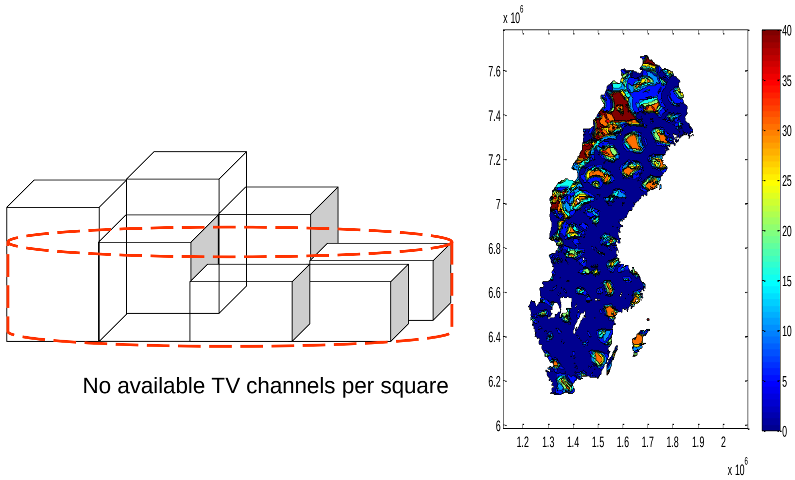



Figure 3-3: Number of available TV channels is estimated for geographic squares (estimates from QUASAR deliverable D5.1) for a transmit power of 4 W.

### 3.2.5 **Business analysis**

*Cost structure analysis*

A high level cost structure modelling and analysis will be used. The cost structure of the radio access network is modelled by using three main components: the radio equipment, the base stations sites and the transmission [Johansson07]. The impact of spectrum prices will be discussed according to the model in [MGSM12].

The cost of the cognitive radio equipment is not known but a high level cost-capacity comparison with state-of-art the equipment for mobile broadband is done. A detailed cost structure model for the cognitive radio system is for further studies. In addition to the radio transceivers it also need to include functionality for sensing and control of the spectrum, geo-location data bases, etc. For different approaches for secondary use of spectrum the impact of system bandwidth will be considered.

*Business feasibility analysis*

The business feasibility analysis is based on comparison between different business scenarios, the approach is presented in [MarCas12]. The key elements for comparison are found in the business model definition proposed by Chesbrough and Rosenbloom [Cheros02]. The business model definition contains the following elements: i) The value proposition, ii) the market segment, iii) the cost structure and profit potential, iv) the firm organization and value chain, v) the competitive strategy and vi) the position of the firm in the value network.

In the analysis we focus on the three first elements of the business model definition. Note that the definition by Chesbrough and Rosenbloom just provides a structure for describing the business model, nothing is said about how to evaluate and compare different businesses. In the analysis in section 3.4 the key aspect is the amount of investments an actor need to make in order to provide a certain amount of capacity.

In section 3.4 and 3.5 we provide more additional descriptions on used analysis approaches, methodology and data collection.

## 3.3 **Analysis from a cost and capacity perspective**

### 3.3.1 Demand and offered capacity

We consider cases where few TV channels are available, e.g. one and four TV channels correspond to 8 and 32 MHz few channels. This can be compared to the deployment of 800 MHz networks with bandwidth in the range of 5 MHz to 20 MHz. In table 3-1 we presented examples of the user demand depending on the number of users per area unit and the usage level per user. The user demand in these scenarios, expressed as Mbps per km$^2$, is compared to the offered capacity. The assumed bandwidth (BW) is in the range one to four TV channels and the spectral efficiency (SE) is in the range 0,25 to 1,0. As mentioned in section 3.2, the key parameter for the capacity estimates is the product SE*BW, see table 3-3. We have assumed deployment scenarios where the cell size differ an order of magnitude when it comes to coverage area.

The comparison indicates that for the assumed usage and user densities and coverage areas of sites the demand can reasonably well be met with bandwidth corresponding to a few TV channels. With 32 MHz quite high demand levels can be met. When demand and supply can be matched the deployment strategy needs to be examined in more depth. The cell size and the site density need to be considered from a cost perspective, see the next section on analysis of cost and cost structure.

Table 3-3: Examples of user demand and offered capacity per area unit assuming different coverage areas per site and spectral efficiency*bandwidth (SE*BW).

| Type of area | Number of users per km$^2$ | Area demand (Mbps/km$^2$) | Coverage area per site (km$^2$) | Capacity (Mbps/ km$^2$) for varying SE*BW 2 | 8 | 32 |
|---|---|---|---|---|---|---|
| Rural | 10 | 0,1 - 1,0 | 100 km$^2$ | 0,06 | 0,24 | 0,96 |
| Suburban | 100 | 1,0 – 10 | 10 km$^2$ | 0,60 | 2,4 | 9,60 |
| Urban | 1000 | 10 – 100 | 1,0 km$^2$ | 6,0 | 24 | 96 |
| Metro | 10000 | 100 – 1000 | 0,1 km$^2$ | 60 | 240 | 960 |

The comparison indicates that the specified demand levels (with the assumed cell sizes) can reasonably well be met with a bandwidth corresponding to a few TV channels. With 32 MHz quite high demand levels can be met. There are however a number of comments:

- When demand and supply can be matched the deployment strategy needs to be examined. The cell size and the site density need to be considered from a cost perspective; see section 0 on analysis of cost and cost structure.
- In rural area very few MHz are needed in order to satisfy the demand. Of course the cell size can be increased (if possible from a transmit power perspective), but this lead to lower average spectral efficiency, see Figure 3-2. Hence, one can argue if there is a lack of spectrum in rural areas. Another issue to discuss is if there is a business case for MBBA in rural areas based on secondary use of spectrum using an own infrastructure. Options could be to buy capacity from another operator (i.e. MVNO operation) or to share network.
- For indoor deployment using femtocells the need for high bandwidth need to be analysed in depth. The capacity of femtocells is shared by a number of users but it turns out that the capacity corresponds to a (too) large number of users. 5 MHz femtocells are reported to offer bit rates above 40 Mbps, i.e. a spectral efficiency > 8 bps per Hz. Even with lower spectral efficiency femtocell deployment may result in over-provisioning of capacity. With spectral efficiency of 2 bps per Hz a 5 MHz femtocell offers capacity corresponding to 100 users consuming 10 GB per month or 1000 users consuming 1 GB per month. For the deployment and spectrum allocation both capacity and user data rates need to be considered.

For femtocell deployment it would be feasible to use a relatively low bandwidth and still be able to serve a large number of users [Marmäk10].

This could be exploited by using a re-use factor larger than 1 and hence improve the inter-cell interference. Alternatively, more spectrum can be allocated to macrocells. As proposed by Mäkitalo the over-capacity can be used to offer bit rate guarantees [Marmäk10].

### 3.3.2 Deployment and equipment cost

We can compare MBBA using TV white space with MBBA deployment in the 800 MHz band. Although the uncertainty is high, when it comes to estimation of costs for cognitive radio equipment, some insights can be gained if we consider the overall cost structure for MBBA deployment. In Figure 3-4 we consider two main components of the cost structure for a radio access network; the radio equipment and "the sites and transmission".

The cost for deployment of a macro base station site is typically in the 50 – 200 k€, in the examples in Figure 3-4 will assume the cost 100 k€ for deployment of a new site. If an existing site is upgraded with a fibre connection the cost is estimated to be 20k€ per site (according to Telenor in Norway[4]).

The cost-capacity ratio of commercial radio equipment has improved more than 20 times the last few years. This is illustrated in Figure 3-4 where HSPA and LTE are compared. For cognitive radio we still do not have any cost numbers, hence the uncertainty. Factors that may drive costs for cognitive radio are: wide system bandwidth, additional systems for sensing, data bases, etc., and no large scale production.

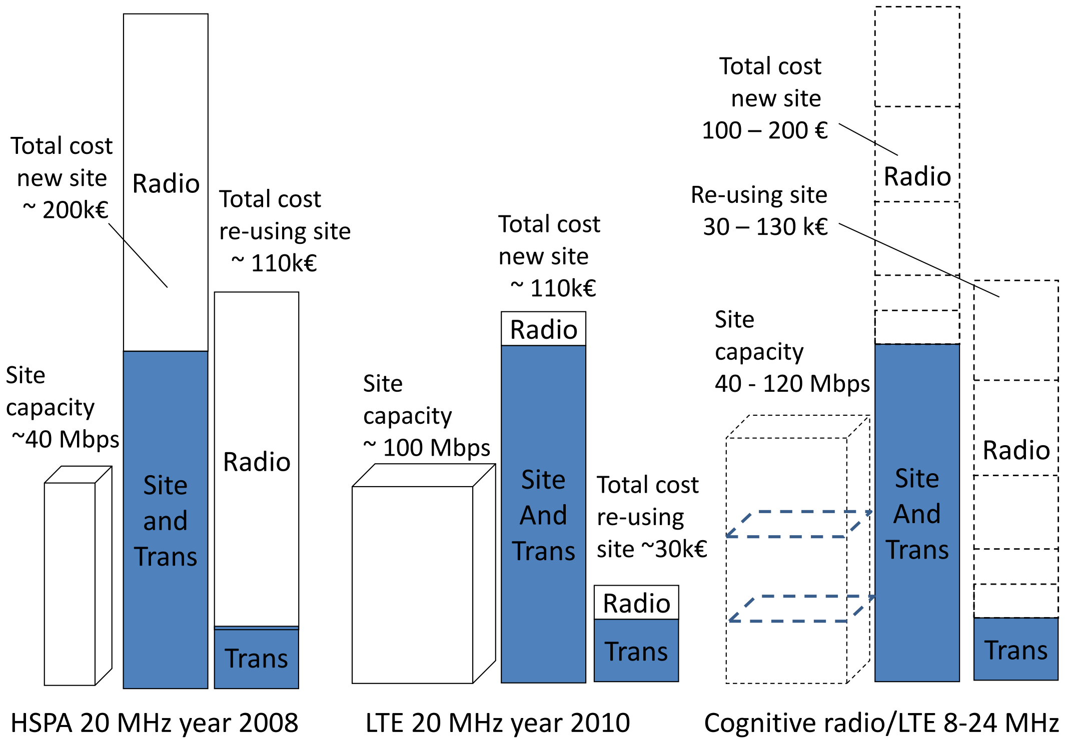



Figure 3-4: Example of cost structure for different types of radio access technologies. For the cognitive radio solution the indicated variation in capacity depends on the available bandwidth and the variation in costs for radio equipment depends on uncertainty.

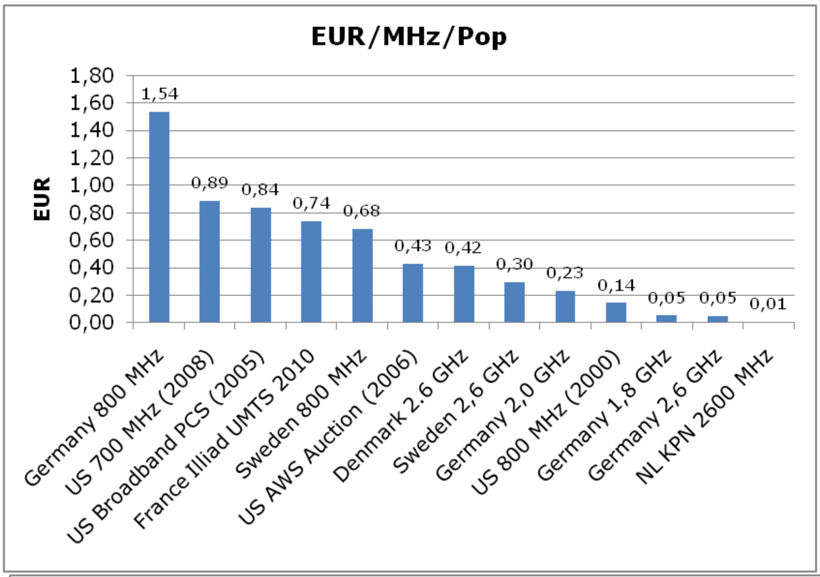
4 www.telenor.com/en/resources/images/cmd10-02-2-rolv-erik-spilling-modernisation-of-themobile-network_tcm28-56164.pdf

From Figure 3-4 we can draw one conclusion: even if the cost for cognitive radio equipment would the same as for standard LTE base stations, the key issue is if new sites need to be deployed or not. In this case the problem is mostly a matter of market entry. In addition to deploying a new network, a new actor needs to invest in marketing, customers, customer care, service and billing platforms, and to build up the operation.

For deployment of femtocells one challenge is the very large number of base stations that need to be deployed in order to provide indoor coverage [Marmäk10]. The network cost depends on the density of femtocells [Mdahl11]

### 3.3.3 Cost of spectrum

So far we have considered only network and deployment related aspects in the cost structure analysis. What impact does the cost for acquiring spectrum have? Will it change the situation and answer? The answer is "yes" and "no", it depends on the specific case. First we look into what prices operators have paid for spectrum and next we discuss the impact on the analysis of the business cases and scenarios.



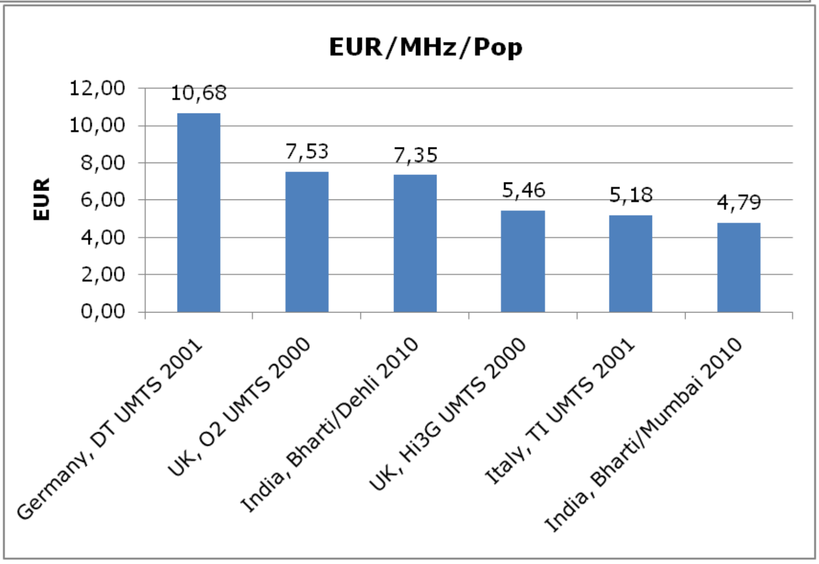




Figure 3-5: Prices paid per MHz/Pop in spectrum auctions and for 3G licenses in India and Europe, from [Mölmar11]. Source: NRAs and calculations by Bengt G. Mölleryd.

*Price for spectrum*
Mölleryd and Markendahl have analysed how spectrum is valued by comparing spectrum auctions prices and the engineering value [Mölmar11]. The engineering value is estimated as marginal savings in network deployment costs having the spectrum compared to not having the same amount of spectrum. The prices paid by operators for a number of spectrum auction are shown in Figure 3-5. The metric used is the auction price normalized with the bandwidth (MHz) and the population, i.e. Euros/MHz/pop.

Typical values for recent spectrum auctions in Europe show a wide range of variations. Mobile operators in Germany paid EUR 1.54 per MHz/pop for spectrum in the 800 MHz band and the Swedish operators in average paid EUR 0.68 per MHz/pop for the 800 MHz band. This can be compare to the prices for spectrum in the 2.6 GHz band that reached EUR 0.30 per MHz/pop in Sweden, EUR 0.05 in Germany and just 0.01 in the Netherlands.

Interestingly enough, prices paid at the Indian 3G auction in 2010 for spectrum in the main two cities, in the range 5-7 EUR per MHz/pop are not far off from prices paid at the 3G auctions in the year 2000-2001. Hence there is a very large variation in spectrum prices, a variation ranging between EUR 0.01 to ~7, this represents a range of almost three orders of magnitude.

*Implications for the business case analysis*
The spectrum costs need to be related to the other components in the cost structure, i.e. radio equipment, transmission and sites. Large variations are identified if we compare three cases: Tele2 buying 2.1 GHz spectrum in the Netherlands, the Swedish 800 MHz auction and the price paid by Bahrti paid in Dehli India for 5 MHz in the 2.1 GHz band. We calculate an estimated average spectrum cost number per site. The exact number of sites needs to be determined but a first order estimate can be calculated assuming 3000 or 6000 sites. The populations in these cases are 17, 14 and 10 Million people.
The results are shown in Figure 3-6, indicating very large differences. For Tele2 in the Netherlands the spectrum cost can be neglected in relation to other costs. In the case from Sweden the spectrum cost is of the same order of magnitude as the radio equipment or transmission and in the case in India the spectrum cost is equally large (or even larger) than the site costs, deployment of mast and towers etc.

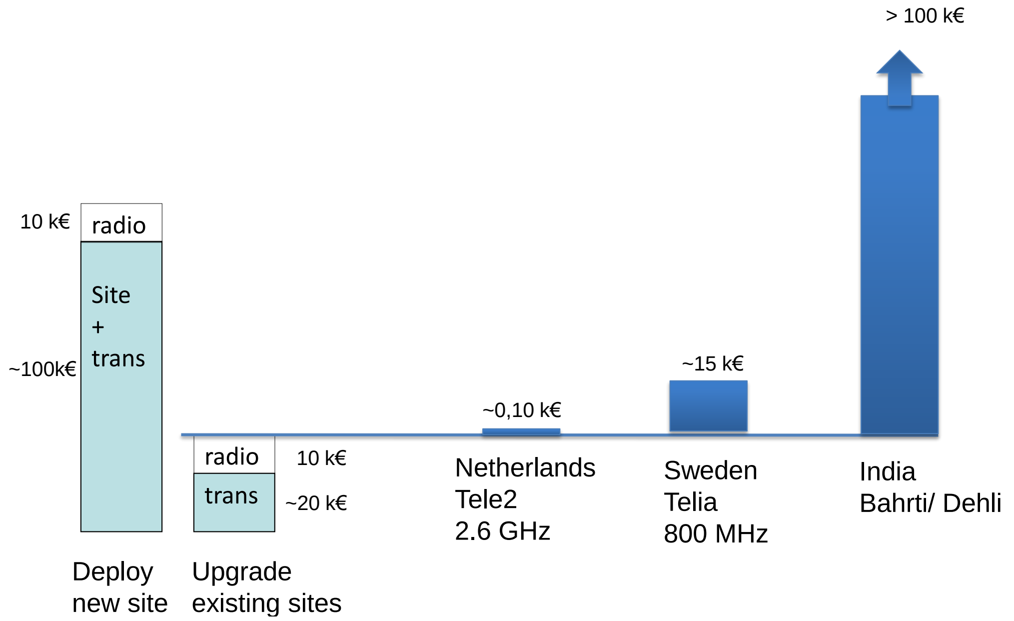



Figure 3-6: Illustration of cost structure with sites, transmission, radio equipment and spectrum costs, costs per base station site for the three examples in the Netherlands, Sweden and India.
Source: NRAs and calculations by Bengt G. Mölleryd and Jan Markendahl.

### 3.3.4 Comparative sensitivity analysis

In order to relate the spectrum costs to other network costs we present a sensitivity analysis with two levels of spectrum prices. A high level is represented by Metro areas in India and a medium level is represented by recent auction in Sweden. We compare network deployment by a market entrant and an existing mobile operator using either licensed spectrum or TV white spaces. Results are shown below where we vary bandwidth or demand levels. First we describe characteristics of the two markets.

In Sweden the mobile operators in comparison with many other parts of the world have large amounts of spectrum. On average operators have almost 70 MHz of spectrum for mobile communication services, see Figure 3-9. Although operators are interested in "more spectrum", there is no general driver to look into solutions with cognitive radio and secondary usage of spectrum, e.g. use of TV white space for mobile broadband. The operators prefer licensed spectrum that can be controlled exclusively. Compared to the prices paid in metro areas in India the spectrum prices are much lower. The capacity demand can be met by deploying many base stations but since there is a high density of existing sites these can be re-used. However, one example where use of TV white space is of interest is when operators in high demand areas instead of deploying new sites using licensed spectrum can re-use existing sites deploying cognitive radio that exploits white space.

For a market like India with low levels of available spectrum in combination with high or very high spectrum prices the use of secondary access of spectrum would be of much larger interest than in a country like Sweden. The differences are illustrated below by two types of sensitivity analysis where we analyze the impact of spectrum price on the operator network cost structure. The key aspect is the relation between the spectrum costs and other network costs related to base station sites, towers, power, transmission, radio transceivers, etc. By comparing prices paid at recent spectrum auctions in different countries we can identify very large differences in spectrum prices, see an accompanying paper to this conference [Mölmar12]. Using the same metric as Mölleryd, spectrum price normalized to number of MHz and the population, we can identify differences one or two orders of magnitudes between auctions in Europe and in the metropolitan areas of India.

Table 3-4: Examples of spectrum prices

| Case | Bandwidth | € /MHz/pop | Spectrum cost /site |
|---|---|---|---|
| Sweden 800 MHz | 10 MHz | ~0,50 | ~10 k€ |
| India 2.1 GHz | 5 MHz | ~5 | ~100 k€ |

In Europe the major network cost component is the deployment of a new site. On average this is ~100 k€ and the cost of LTE radio equipment is roughly 10 k€. From table 3.4 we can see that the spectrum costs for the German case are very low and the spectrum costs for the Sweden case are of the same order of magnitude as the radio equipment, i.e. still a minor part. However, for the India metro case the spectrum costs are of the same order of magnitude as the site costs. This has important implications for the overall cost.

In Figure 3-7 and 3-8 we compare network costs for two types of operators, one incumbent operator with a set of already deployed base stations and a Greenfield operator that needs to deploy all sites. For both types of operators we compare deployment costs using licensed spectrum and white space spectrum. In the analysis by Sanchez [MGSM12] we assumed that the cost of the cognitive radio equipment (TVWS) is twice the one of commercial LTE mobile broadband equipment. This assumption is based on the higher system bandwidths for the CR equipment and larger production volumes for LTE.

First we compare the total costs for the different cases when the available bandwidth increases assuming the spectrum costs derived from the recent auctions. In a country with "swedish levels" of spectrum costs there is an overall decreasing trend for the total costs, see Figure 3-7a. In a capacity limited scenario more spectrum results in a lower number of base stations sites. When spectrum prices are "much higher" the situation is totally different, Figure 3-7b. Initially more bandwidth results in fewer sites and lower costs but for higher levels of bandwidth the total cost start to increase with bandwidth. For both the incumbent and the Greenfield operator there is some kind of optimum parameter set minimizing the cost.

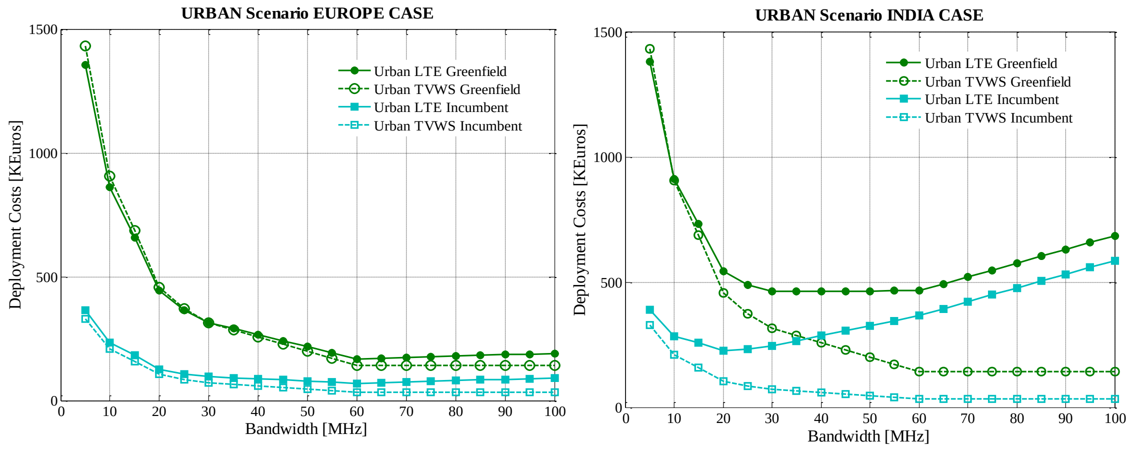



Figure 3-7: Network costs for deployment in urban areas as a function of bandwidth for a) medium level (left) and b) high level (right) of spectrum prices.

The impact of differences in spectrum prices can also be illustrated by varying the user demand levels. In all cases the network costs increase with demand as a result of network build-out. When spectrum prices at a "Swedish" level the incumbent always has a cost advantage, as in Figure 3-8. For high spectrum price levels the actor that uses white spectrum has a cost advantage.
For these levels of spectrum prices use of TV white space spectrum show clear cot advantages and should be investigated in more depth. The specific numbers shown in the graphs depend on our assumptions; the graphs are there in order to illustrate the overall impact of differences in spectrum prices.

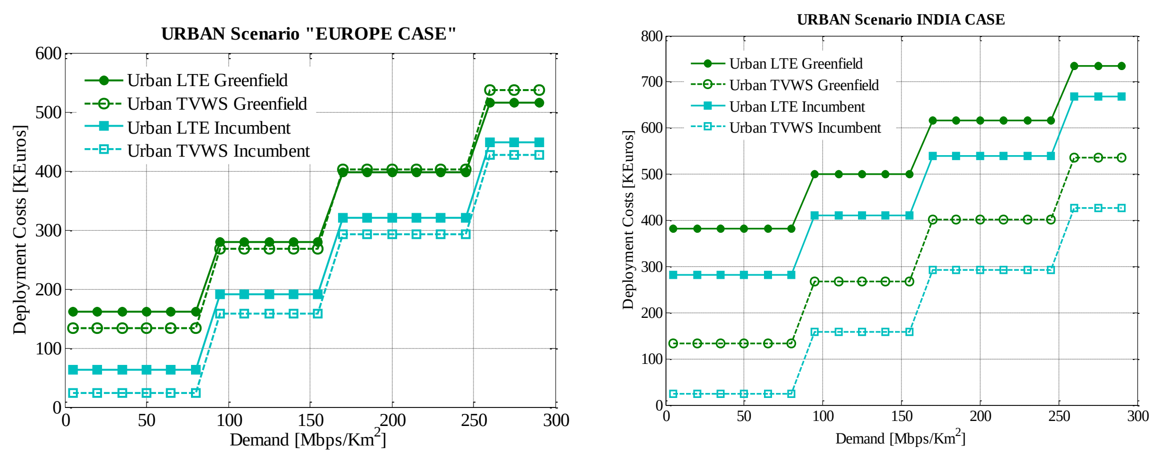



Figure 3-8: Network costs for deployment in urban areas as function of user a) medium level (left) and b) high level (right) of spectrum prices.

### 3.3.5 Drivers for use of TV White spaces in relation to spectrum costs

We can identify a number of drivers for the use of TV white spaces for mobile operators:

3. The overall shortage of licensed spectrum, this is valid for all operators
4. The opportunity to get access to spectrum resources for actors without any licensed spectrum enabling market entry otherwise not possible
5. Since spectrum auctions only happen at certain points in time, the use of TVWS can compensate for missed opportunities at auctions
6. High costs for licensed spectrum, in some regions use of TV white space can be strategy to reduce overall costs and hence improve the business cases.

The fourth driver would be very important in countries where both spectrum prices are high and where operators have low amount of spectrum. Once again, India is a typical example. This is illustrated in Figure 3-9, from [Mölmar11] where the average amount of spectrum per operator is shown for a number of countries.

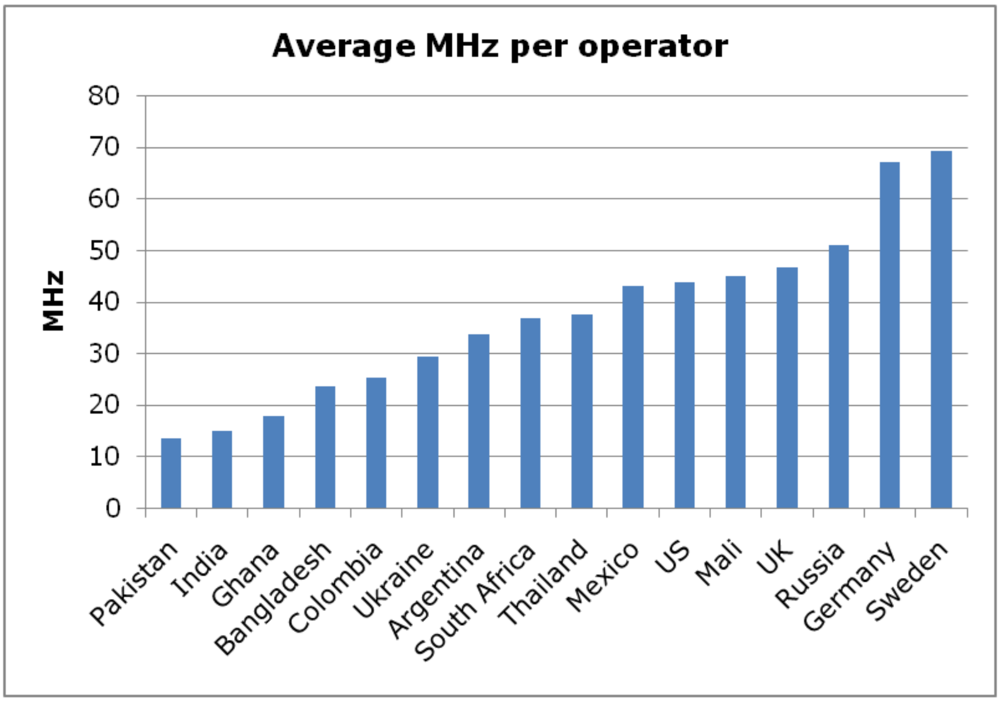



Figure 3-9: Average MHz per operator (downlink)[5], from [Mölmar11].
Source: NRAs and calculations by Bengt G. Mölleryd

When we include the spectrum prices we can clearly identify two main aspects:

- There are  large variation in spectrum prices around the world which make the business analysis country-dependent , we still need to consider "the multitude of multitudes"
- We need to look more into cases where the spectrum cost is very large or even is the dominating cost. A case like India put the use of TV white space in a total different context compared to cases in Europe.

[5] The calculation is based on the total amount of spectrum operators have in the different countries, and then calculated as a market share weighted average per country.

## 3.4 Analysis from market and business perspectives

In this chapter we have so far discussed secondary access of spectrum from a technical, capacity and cost perspective. But we also need to consider which actor will be making use of the secondary access including the market position of that actor. No matter if cognitive radio and secondary access of spectrum is used, in general it is challenging for new actors to provide services at a new market. Market entrants need to invest in infrastructure and marketing and to build up a customer base. In this section we will discuss market entry aspect in general terms and in section 3.6 we will consider different sub-scenarios.

### 3.4.1 Analysis framework related to company strategies and resources

In order to describe market entry aspects we use an *overall cost structure* description, an *added value analysis* in combination with the framework presented by Igor Ansoff for discussion of *different growth strategies* for a company [Ansoff58].

The added value analysis is based on the value proposition element in the business model definition proposed by Chesbrough and Rosenbloom . The Value proposition is the service offer to the end-users that is new and unique compared to what’s available on the market. In the cost structure we consider investments and running costs related to networks, services, customers and marketing.

The so called Ansoff matrix considers growth in terms of firm's present and potential products and/or present and new customers, i.e. four different growth strategies:

- *Market Penetration* - the firm seeks to achieve growth with existing products in their current market segments
- *Market Development* - the firm seeks growth by offering its existing products to new market segments
- *Product Development* - the firms develops new products targeted to its existing market segments and customers
- *Diversification* - the firm grows by diversifying into new businesses by developing new products for new markets

If the market grows, maintaining market share will result in growth. The market penetration strategy, i.e. increasing market shares, is the least risky and diversification is the most risky strategy. Diversification requires both product and market development and may be outside the core competencies of the firm.

We believe that a lot can be learnt from history when different mobile technologies have been introduced in the market. We will use this framework to describe the development of 1G, 2G, 3G and 4G mobile services.

### 3.4.2 Learning from the history of mobile systems

*Introduction of first and second generation mobile systems*

When the first and second generation systems for mobile telephony were introduced the mobility and service coverage represented a very large added value to end-users compared with fixed line telephony. When GSM complemented and later replaced the NMT systems the voice service was more or less the same but the number of user increased substantially.  Although market entrants had to make large investments there was still room for new market actors due to a high level of unmet demand for mobile voice services, see Figures 3-10 and 3-11.

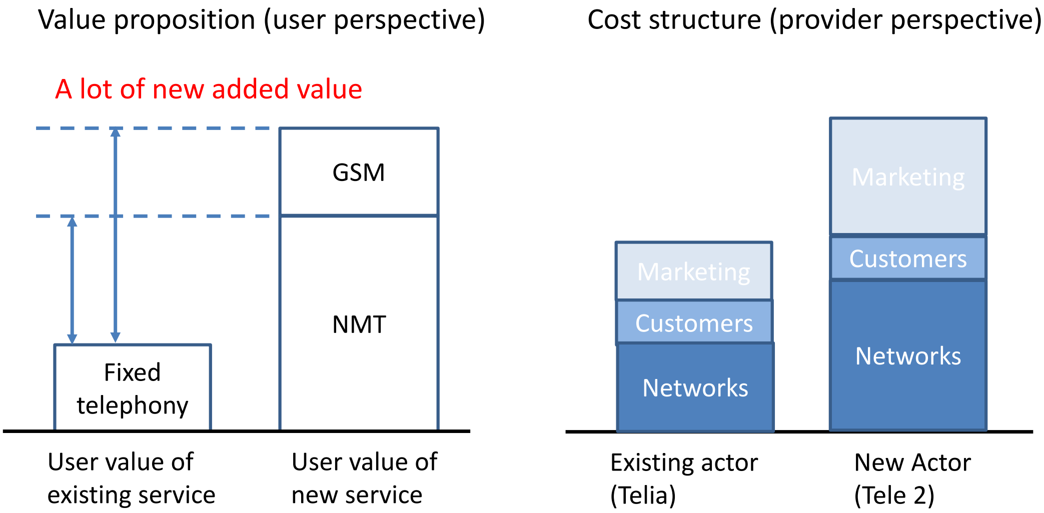



Figure 3-10:User value for telephony service and cost structure for existing and new mobile operators.

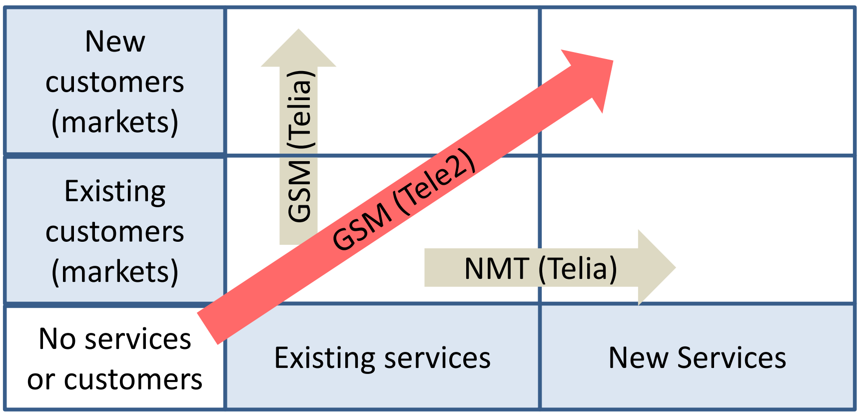



Figure 3-11: Illustration of introduction of NMT and GSM in Sweden using the Ansoff matrix.

*Introduction of third generation systems*

When deployment of 3G systems started in Sweden after year 2000 the situation was different compared to when NMT and GSMA were introduced. There was neither any demand for "3G services" nor any new offered services. Both the existing operators and the market entrant "3" had to make large investments in networks in order to satisfy the promised levels of coverage. Hence, the initial situation was characterized by large network costs for operators but low added value for the end-users, see Figure 3-12. The situation was challenging for the market entrant "3". The situation was changed when the operator "3" started to focus on cheap voice services instead of video calls and media services. The result was that prices for voice services in Sweden decreased substantially.

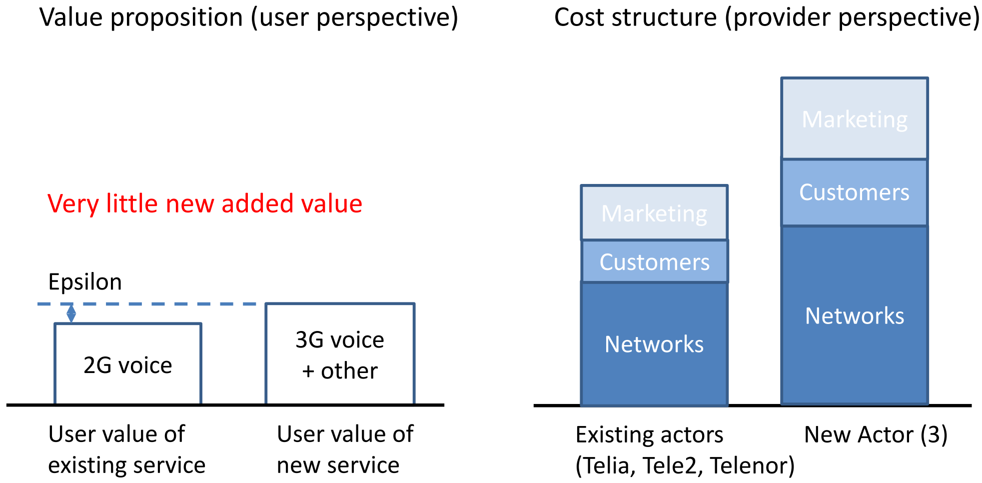



Figure 3-12: User value for "3G services" and cost structure for existing and new mobile operators.

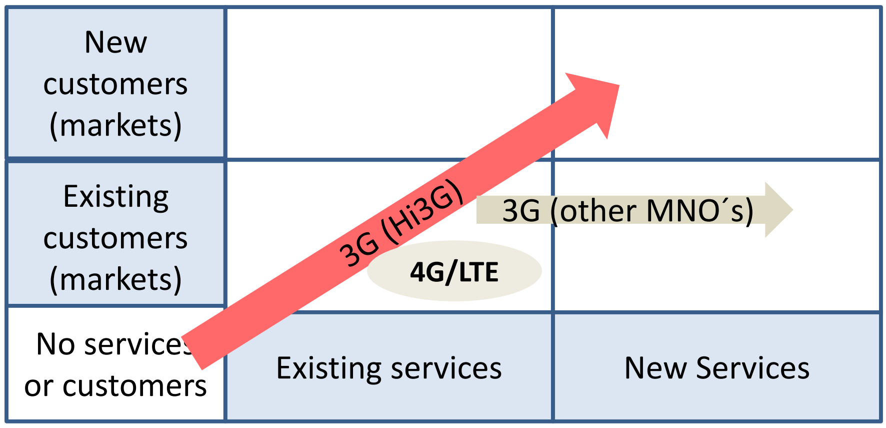



Figure 3-13: Ansoff matrix representation for introduction of 3G in Sweden.

*Development of 3G and introduction of 4G systems*

"3G services" started to take off when mobile broadband was introduced 2006 and 2007. With relatively small investments a high level of added value was offered to the end-users. The base station sites were already there and the costs for upgrading WCDMA to HSPA were reasonable, see Figure 3-14. The introduction of 4G networks (LTE) results in substantially improved cost/capacity performance but it is still the same type of service – mobile broadband access, see Figure 3-13

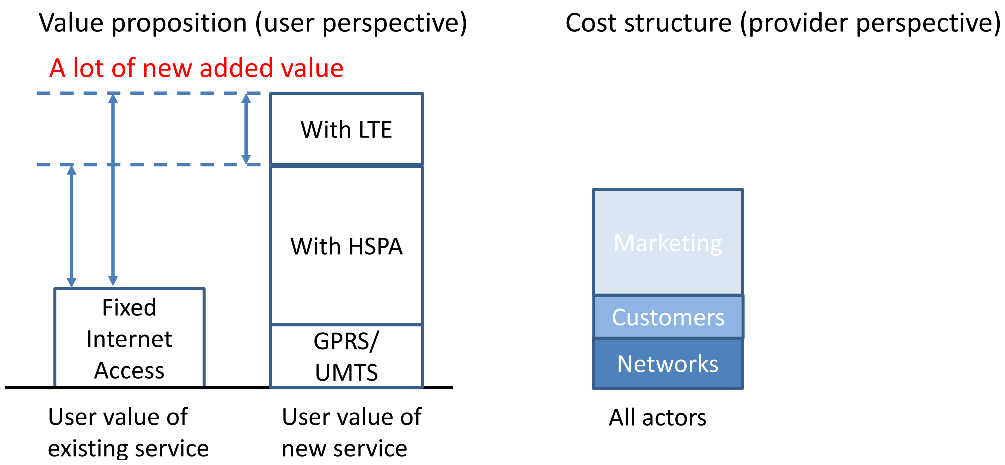



Figure 3-14: User value for mobile data services and cost structure.

### 3.4.3 Analysis of cognitive radio and white space usage

Here we compare two types of mobile network operators, existing operators with licensed spectrum (using white space spectrum as a complement) and new operators without any licensed spectrum using white space spectrum only (i.e. as the only spectrum resource). In both cases the service is mobile broadband access, the relative end-user value depends on the amount and availability of white space spectrum.

In the case of substantially more available white space spectrum than the assumed 10-20 MHz of licensed spectrum then the user experience may be better otherwise not, see the left hand side of Figure 3-15. When it comes to the cost structure the new actor needs to invest in networks and marketing, see right hand side of Figure 3-15. This is similar to the 2G and 3G cases shown above and using the Ansoff matrix representation we can see the similarities of Figure 3-16 and all other figures illustrating market entry.

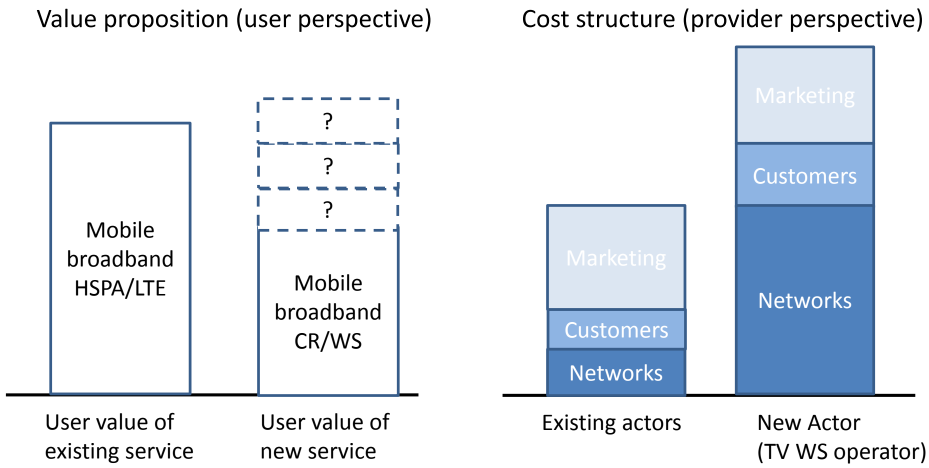



Figure 3-15: Illustration of generic user value and cost structure for mobile broadband services for an existing operator with licensed spectrum and a new TV white-space-only mobile operator.

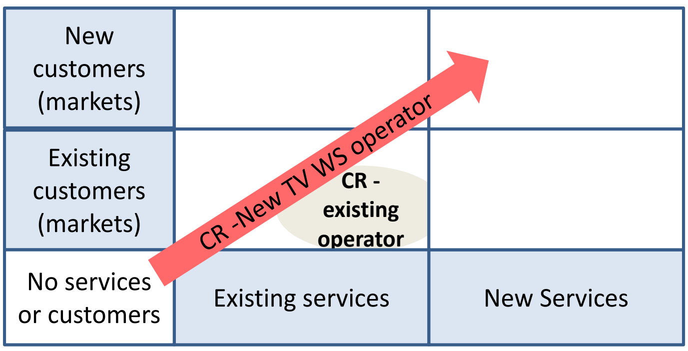



Figure 3-16: Ansoff matrix representation for services based on CR technology for existing mobile operator and for new actor, a TVWS operator.

## 3.5 Complementing analysis for indoor scenarios

For provisioning of mobile broadband services in a local area environment, typically at indoor locations, we present an extended asset analysis in order to highlight differences between different sub-scenarios. The business analysis in the previous sections of this chapter has considered wide area networks. Here the operators can act quite independently when it comes to the deployment and operation of networks. For local area systems this is different since the actor providing wireless access usually needs to cooperate closely with other actors. Typically this can be owners of buildings and infrastructure, companies that use the buildings and enterprises with offices.

In addition, there are different types of *services settings*, e.g. offload, that needs to be considered. Hence, there are many sub-scenarios for the business analysis of use of TVWS in indoor locations. The assumptions for each sub-scenario are important and below we first present the assumptions ("setting the scene" for the analysis). Next, a brief note on methodology is included. Then, an asset analysis is presented for different actors in different sub-scenarios where we compare use TVWS with service provision using licensed and unlicensed spectrum. Finally, we add comments on other benefits of use of TVWS specific for indoor systems.

Please note that the business feasibility analysis in this section in addition to use of TVWS also includes secondary access of radar and aeronautical bands. Hence, we also cover the QUASAR services scenarios *Secondary spectrum commons in radar band* and *Indoor broadband using aeronautical band.*

### 3.5.1 Setting the scene for the analysis of indoor solutions

In order to compare solutions using secondary use of spectrum in different scenarios with existing and competing solutions we here first state the working assumptions.

*Availability of spectrum*

For indoor locations the availability of spectrum bands for secondary use is good compared to outdoor locations, this is valid for TVWS and for radar bands [D5.3]. Since we consider small cells with limited number of users this implies that we will not run into any problems with capacity, see the demand and capacity analysis in section 0.

When it comes to the use of licensed spectrum operators seem to be unwilling to allocate specific bands for indoor locations. When the same frequencies and bands are used for both wide and local area deployment interference problems arise, see 0.

Here we should also mention the allocation of unlicensed spectrum in the 1800 MHz band in countries like Sweden, The Netherlands and the UK. This enables new actors to deploy pico- or femtocells and offer GSM-services. In Sweden currently a 1,8 MHz band is allocated and specifically for GSM-services, discussions are ongoing to increase the bandwidth to 5 MHz and to make the band technology neutral.

*Equipment and spectrum bands*

We consider mobile broadband services based on LTE type of technology. We assume that access points and user equipment for secondary use of spectrum are based on commercially available solutions in bands close to 800 MHZ and 2.6GHz. However, this is an important issue to investigate further.

We would just again mention the implications of allocation of unlicensed spectrum in the 1800MHz band. Since there are a very large number of GSM phones using 1800 MHz, a new actor deploying an 1800MHz network can offer services from day one to many potential users. This is of interest in local area environments similar to WiFi hot spot operation, especially if 5 MHz of unlicensed bands will be made available.

*Service setting, who is providing what to whom*

Indoor wireless access can be considered in different services settings depending what actor that is providing what kind of service, and to what type of customer.

- Business to Consumer(B2C)
  Services offered direct to individual users, e.g. public WiFi offered in hot spots
- Business to Business (B2B)
  Services offered to companies and their employees, e.g. private WiFi networks
- Business to Business to Consumers (B2B2C) – Offloading
  Indoor capacity offered by a local operator to a mobile operator
- Business to Business to Consumers (B2B2C) – Roaming case
  Indoor capacity offered by a mobile operator to another mobile operator

*Actors and resources*

The key findings are based on analysis of what resources that are needed in different service settings and what resources and assets different actors have – and not. We consider the following actors:

- An existing mobile operator with licensed spectrum and with an already built up business with networks, organization and customer base, indoor access services will be provided to own users or to roaming partners
- An existing Mobile Virtual Network Operator (MVNO) with an already built up organization, customer base and core network, but no licensed spectrum or radio access network. Services will be provided to own users or to roaming partners
- A TVWS only operator that will enter business and build up resources. The indoor access services will be provided to own customers or as offloading
- An existing hot spot operator offering WiFi services and will use secondary access of spectrum to offer extended hot spot services. The indoor access services will be provided to own customers or as offloading
- A facility owner that will act as a local operator and offer local access services to consumers, business or to operators as offloading

### 3.5.2 Approach, methodology and data collection

The approach is based on analysis of the resources that different actors need to acquire and control in order to be able to offer services in different scenarios. It is the same type of approach that is used for the analysis of wide area systems, see 3.3 and 3.4. This analysis builds upon previous business analysis made for WiFi-services and operators [Marmäk07] and femtocells [Marnil10].

The analysis is based on data collected at interviews made with different types of actors both in 2010 [Mdahl11] and at follow-up interview sessions in 2011 and 2012. The findings in this report are based on interviews with the following actors

- Regulators (Swedish Post and Telecom Authority, Ofcom)
- Mobile Operators (Tele2, TeliaSonera)
- Hot spot/local area operators (The Cloud, Clue, SpringMobil, SJ)
- The large manufactures of telecom networks (Ericsson, NSN, Huawei)
- Manufacturers of subsystems (Powerwave, Commscope, Icomera, IP Access)
- System integrators (Absolute Mobile, MIC Nordic)
- Facility owners (Jernhusen, The Swedish Parliament, KTH, Uppsala University)

### 3.5.3 Analysis of service options and resources of different actors

*An existing Mobile Operator*

An existing mobile operator with an ongoing business with services, a customer base and already deployed macro base stations would like to offer indoor capacity. The data services can be offered by cellular systems using licensed, unlicensed or TVWS or radar bands or by WiFi networks using unlicensed bands. One driver for Mobile operators to use unlicensed or TVWS bands is to avoid interference between macrocell and pico/femtocell layers using the same (licensed) bands, see section 0.

The indoor capacity is offered to own users or to other operators by use of some kind of national roaming agreement. The mobile operators have resources available when it comes to management of users and traffic, CRM and billing platforms and core network nodes. The extra cost is for deployment of the indoor capacity: access points, transmission and installation. These cost components are valid no matter if licensed, unlicensed or TVWS is used, the open issue is if TVWS access points will be available. From a business perspective it does not matter if the operator make use of licensed, unlicensed or TVWS spectrum, the end-users do not need to know what bands are used. This conclusion is based on the assumption that TVWS equipment will be available at large scale and at reasonable cost.

*An existing Mobile Virtual Network Operator (MVNO)*

An existing Mobile Virtual Network Operator (MVNO) with an ongoing business with services, a customer base, a core network would like to offer indoor capacity. The services can be offered by cellular systems using licensed spectrum leased from another operator, unlicensed or TVWS bands or by using WiFi networks using unlicensed bands. Operation of networks using unlicensed or TVWS bands provides an added value and independence to the MVNO since they do not have any own spectrum.

The indoor capacity can be offered by the MVNO to own users (subscribers) or to other operators. The MVNO has resources to manage users and traffic, e.g. CRM and billing platforms and core network nodes, i.e.B2C service are already offered. The deployment of the indoor network means costs for access points, transmission and installation.

*A new TVWS only operator*

Here we consider a TVWS only operator that will enter business and build up resources. From the analysis in previous sections we can conclude that a new actor that enters the market has a challenging situation due to all investments and competition from existing actors. However, the case where only indoor access services will be provided would be more favourable to the new actor from a market entry perspective compared to a case where national (or wide area) coverage is considered. For local area access the business can be build up in steps, no national coverage is needed. The TVWS operator can act as a hot spot operator. A key issue will be the availability of CR equipment.

We can identify difference in costs related to the type of services. B2C services require more investments in CRM and billing platforms compared to B2B services offered to companies. The latter is similar to a company WiFi network operated by a third party. Offloading to multiple operators is more complex than offloading to a single mobile operator. One mobile operator can use TVWS indoor capacity provided by other actors as an extension of the own network, the radio access control and core network of the mobile operator can be used. For offloading to multiple operators some kind of roaming solution would be needed and the TVWS operator would need to have a core network, a network code etc.

*An existing WiFi hot spot operator*

Here we look into an existing hot spot operator offering WiFi services that considers the use of secondary access of spectrum in order to enhance capacity. The hot spot operator has resources to manage users and traffic, e.g. CRM and billing services and platforms, Internet connectivity to the hotspots and agreements with the owners of the hotspots (e.g. hotels, coffee shops, railway stations). The indoor capacity can offered to the own users or as offloading services.

The key question in this case is what kind of technology the hot spot operator should make investments in and deploy. Should the hot spot operator deploy a denser WiFi network using established and well known technology or should it use some kind of cognitive radio solution using TV WS, aeronautical or radar bands? The development of IEEE 802.11af using TVWS ("white-Fi") would be very interesting for this kind of actor, especially when more capacity than offered by existing WiFi networks is needed[6].

If a non-WiFi solution is of interest use of the 1800 MHz would be a candidate. LTE networks for 1800 MHz are currently deployed, e.g. in Denmark[7].

*A facility owner acting as local operator*

In this case we consider a facility owner that will act as a local operator and offer local access services to consumers, business or to operators as offloading. The assets that this type of actor has are: access to connectivity, cheap installation and also access to potential users within the building, e.g. companies that are tenants.

On the other hand a facility owner or manager needs to build up a radio access network. In this case B2B services to tenants or offloading services are more feasible than public B2C services directly to end users. The facility owner would need to deploy resources to attract customers and to manage users and traffic, e.g. help desk, CRM and billing services and platforms. If this local operator would offer cellular roaming services, core network capabilities would be needed. All in all, a lot of investments are needed and to provide wireless access services is outside the core competence and business.

Using the same reasoning as for a hot spot operator, the driver for a facility owner to use a CR solution would be very low. Local access services can be provided using WiFi technology or unlicensed cellular spectrum. Use of CR can be considered provided that commercial CR equipment is available and integrated in smartphones, laptops, WiFi and femtocell access points.

*A note on geo-location data bases and the selection of spectrum bands*

For indoor locations the availability of spectrum is shown for TV, aeronautical and radar bands (D5.3). The secondary access requires a geo-location database. For TVWS this can be assumed to be static but for aeronautical and radar bands the data base needs to be updated on a second or minute basis due to the movement of aircrafts and the rotation of radar antennas. This may imply a quite complex geo-location system to collect, to process and transmit the data, i.e. a system that needs to designed, deployed and managed by other actors.

In addition, to pay for the access to the geo-location data base an operator making use of the aeronautical and radar bands needs to have some level of network control taking into account the variations in available spectrum. The complexity of such a network control needs to be investigated, but it can be concluded that a mobile operator would be more capable to manage such a system and include it in the network control. For smaller actors this would be more complicated and less feasible.

[6] http://www.radio-electronics.com/info/wireless/wi-fi/ieee-802-11af-white-fi-tv-space.php
[7] http://www.telecoms.com/29582/lte-network-plans-europe/

*Summary of the actor resources analysis*

Similar to the analysis of outdoor macro deployment new actors need to build up "more" resources than existing operators in order offer the services. Existing mobile operators, MVNOs and hot spot operators already have some resources and assets that can be re-used whereas TVWS only operators and facility owners that want to act as local network operators need to invest more.

However, use of secondary access of spectrum at indoor locations is different to outdoor macro deployment since the availability of secondary spectrum is much larger. Local network operation also differs from wide area network operation in some aspects:

- The business can start on a local basis and be expanded in steps, there is no need for national coverage from the start.
- Control of the local environment and agreements with the facility owners are essential since it is very unusual that multiple networks are deployed indoors.
- Due to the control of the local environment (a kind of local monopoly) the type of customers and degree of contact with end-users are different since there can be
    - Business to Consumer(B2C) services offered direct to individual users
    - Business to Business (B2B) services offered to companies
    - Business to Business to Consumers (B2B2C) services where the indoor capacity is offered other actors in an offloading or a roaming setting

Based on the analysis of service options and resources of different actors we provide a summery in table 3-5 below where we estimate the position of different actors for different service settings and also the perceived value of use of secondary spectrum. The actor position assumes deployment of an indoor network using CR and secondary access of spectrum.

Table 3-5: Estimation of the position of different actors and services types for indoor deployment of networks using secondary access of spectrum. The last column indicates the perceived relative value of use of secondary spectrum considering other competing solutions.

| Actor/ Service type | Access Network | Core Network | Sites and transmission | CRM and Billing | Value of CR & WS spectrum |
|---|---|---|---|---|---|
| Mobile op | | | | | |
| /B2C | Strong | Strong | Weak | Strong | Low |
| /B2B | Strong | Strong | Strong | Strong | Low |
| /B2B2C | Strong | Strong | Weak | Strong | Low |
| MVNO | | | | | |
| /B2C | Weak | Strong | Weak | Strong | High |
| /B2B | Weak | Strong | Strong | Strong | High |
| /B2B2C | Weak | Strong | Weak | Strong | High |
| TVWS op | | | | | |
| /B2C | Weak | Weak | Weak | Weak | High |
| /B2B | Weak | Weak | Strong | Weak | High |
| /B2B2C | Weak | Weak | Weak | Weak | High |
| Hot spot op | | | | | |
| /B2C | Strong | Weak | Strong | Strong | Medium/high |
| /B2B | Strong | Weak | Strong | Strong | Medium/high |
| /B2B2C | Strong | Weak | Strong | Strong | Medium/high |
| Facility owner | | | | | |
| /B2C | Weak | Weak | Strong | Weak | Low/medium |
| /B2B | Weak | Weak | Strong | Weak | Low/medium |
| /B2B2C | Weak | Weak | Strong | Weak | Low/medium |

### 3.5.5 Other types of benefits

When it comes to femtocell deployment for secondary use of spectrum two other general benefits can be identified. The benefits that are related to the secondary use of spectrum itself rather than specifically use of TV white space. The key issues are:

i) That the cellular technology can be used, i.e. at frequencies that will be supported by telecom industry,

ii) That the band of interest is separated from the bands that are used for macrocellular networks

iii) That the frequency band is not controlled by any mobile operator. Hence, it can be a band where secondary access is used or an unlicensed band

For mobile operators the joint deployment of femtocell and macrocell base stations results in interference and co-existence problems [Espino10]. One such problem is the so called dead zones or coverage holes created around femtocell for user terminals connected to macro base stations using the same or adjacent frequency channels. This occurs for femtocells using access strategies where only specific user groups are allowed to access the femtocell. A typical use case can be where employees can access femtocells at their home office but the visitors at the office are not allowed to do so.

With femtocells and macrocells operating at bands well separated in frequency the interference problems are removed. Hence, dedicated bands for femtocell deployment are beneficial from an interference point of view. Operators are less willing to allocate dedicated spectrum bands for femtocells since they want to use as much as possible for macrocell deployment. Both unlicensed bands, e.g. in the 1800 MHz band, and TV white space fulfil these requirements.

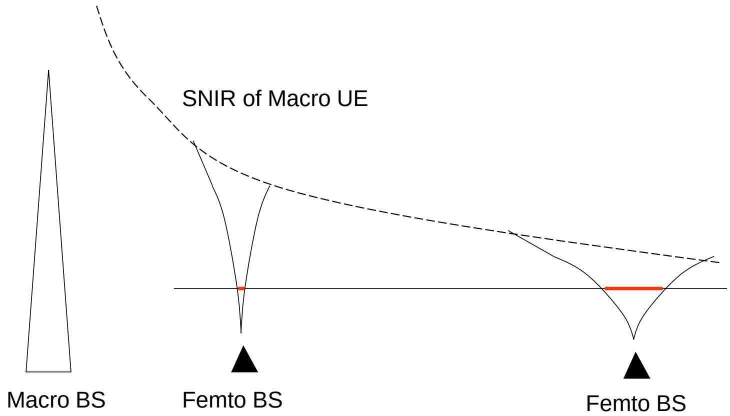



Figure 3-17: Illustration of dead zones appearing in the vicinity of femtocells.
Due to the short distance to the femtocells the user equipment cannot connect to macro base stations

Facility owners can deploy and operate indoor wireless networks for their customers and for mobile operators, often in cooperation with the mobile operators. The drivers for dedicated indoor system can be problems with wall penetration losses using outdoor base stations or that the users in the building want dedicated and ensured capacity. Shared indoor infrastructure is very common when so called "distributed antenna systems (DAS) are used. The radio transceivers of all operators (that want to join) are placed in an equipment room and the radio signals are distributed within the building using a built-in distribution network. In this case the operators use their own base stations and their own licensed frequencies [Mdahl11].

The advantage with a common and shared femtocell network using TVWS, a dedicated licensed frequency band or an unlicensed band would be that operators will avoid interference problems and at the same time can use all "own" spectrum for macro base stations [Espino10].

## 3.6 Results for different sub scenarios

Based on the analysis of demand, offered capacity and cost structure described above we can make some conclusions about using TV WS for mobile broadband access services for the selected business cases.

### 3.6.1 Wide area access in rural areas provided by a *TVWS only* operator

In this case a new actor plan to deploy macro cells and use TVWS in order to provide mobile broadband access services. Also here we have the same problem and challenges related to market entry and the need to invest in new base station sites. Options to reduce network costs could be to share networks or to simply buy capacity from another operator, i.e. to be a MVNO.

Another issue for MBBA in rural areas is if there really is a need at all to use TV white space, i.e. the situation differs from the case in urban areas where operators would like to have more licensed spectrum. From table 3-3 we can see that the user demand expressed as Mbps per $km^2$ is very low. In rural areas 5-10 MHz of licensed spectrum in the 800 MHz band quite well satisfies the user demand using existing site grid. With more bandwidth the cell size can of course be increased, but this lead to lower average spectral efficiency, see figure Figure 3-1.

### 3.6.2 Wide area access in urban areas provided by a mobile operator

In this business case we consider an established mobile operator with allocated spectrum and existing sites. In urban areas the user demand is high, the more spectrum that is available the fewer sites needs to be deployed. This type of actor can use TV WS as complement for capacity expansion in urban areas including public hot-spots. The deployment of new sites can be delayed or eliminated by the secondary use of spectrum. Provided that the operator has existing sites that can be used, sufficient spectrum is available and that the cost for the cognitive radio is reasonably low then this business case has a good potential.

### 3.6.3 Wide area access in urban areas provided by a *TVWS only* operator

A TVWSO (without any own licensed spectrum) will use own infrastructure and TV WS in order to offer MBBA services in urban areas. As seen from Figure 3-4 and the related comments this is a difficult business case if new base station sites need to be deployed. Since it is a new market actor the main problem is not about the radio costs, the key issues are related to market entry and large investments in infrastructure, services, billing platforms and processes, marketing, customer relations, customer care etc.

In addition, even if the cost for cognitive radio equipment is reasonable the TVWSO will always be in difficult situation compared to other actors. See Figure 3-18 where a mobile operator makes a certain investment in order to guarantee certain network capacity. A TVWSO will most likely get less capacity for the same level of investment, or will need to invest much more in order to guarantee the same amount of capacity. A MVNO is also shown with low initial investments needed in order to get some level of capacity.

However, this reasoning applies to cases like in Western Europe where the spectrum prices much lower than the cost for network deployment and operation. In cases like in India where the spectrum costs are equal or larger than the network costs, see 3.3.3, another type of analysis needs to be done. Hence, this is an important work item for further research in the QUASAR project.

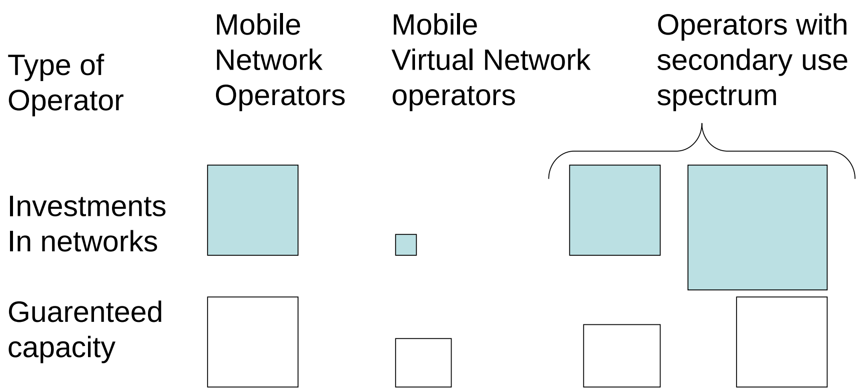



Figure 3-18: Comparison of investments and capacity for a mobile operator, a MVNO and a TVWSO.

### 3.6.4 Local area access provided by a local operator

In this scenario a local network operator will use TV WS and an own indoor infrastructure in order to offer ”indoor” capacity to mobile operators or to own customers within the facilities. Here we consider both an existing WiFi hot spot operator and a facility owner that would like to extend its business to also provide wireless access service. The hot spot operator is assumed to have an existing business with marketing, CRM and billing platforms while the facility owner has to build up all these resources. In both cases B2B or offloading services would require fewer resources than public B2C services. These actors have a strong position when it comes to control of the local environment, i.e. the building and indoor connectivity and access to potential users.

However, these two types of actors the value of use secondary access of spectrum is believed to be low. First, there exist other solutions targeting indoor environments, WiFi solution using the ISM bands and unlicensed cellular bands. Second, there is a high uncertainty regarding the potential availability of CR user and network equipment. Hence, these actors can offer local area access but it is not dependent on the use of CR or secondary access.

### 3.6.5 Local area access provided by a MVNO or a *TVWS only* operator

These types of operators without any licensed spectrum can use TV WS (or unlicensed spectrum) and deploy an indoor infrastructure in order to offer ”indoor” capacity to own users or to other  operators. The MVNO has an existing business with core network, marketing, CRM and billing but the TVWSO needs to build up these capabilities.

The value of the available spectrum in the TV bands (or in aeronautical or radar bands) is believed to be high, provided that CR equipment is available. This means that these actors can act more independently in relation to mobile operators. The MVNO or TVWSO can offer the indoor access as an extension to the assumed wide area services that these actors are assumed to provide. The local area business is beneficial since it be expanded in steps in towns and regions.

### 3.6.6 Local area access provided by a Mobile operator

A mobile operator has a strong position when it comes to provisioning of indoor access services. The operator can use cellular technology using licensed, unlicensed or TVWS spectrum or even WiFi solutions for offloading. Licensed or unlicensed spectrum using existing cellular bands and equipment would be the preferred solution.

Use of unlicensed and TVWS bands will offer a benefit since no or less interference will be introduced between macrocell and femtocell networks.

## 3.7 **Conclusions and implications**

We have analyzed a set of business cases where a mobile operator makes use of TV white spaces in order to offer mobile broadband services. This set of business cases can be seen as snapshots of all possible scenarios but some general conclusions can be made:

1. New actors that need to deploy totally new network with base stations sites, radio equipment and transmission are faced with higher costs than established operators. This conclusion applies for all market entrants, i.e. in our analysis for the TV WS operators deploying networks in the rural and urban areas. For mobile broadband access services existing operators can e.g. deploy a LTE network by just upgrading existing sites with new radio equipment. The problem with high costs for deploying new sites exists even if the cost for cognitive radio equipment should be at the same level as LTE equipment. For the case that cognitive radio is substantially more expensive the business case is even worse.

2. The secondary use of spectrum at indoor locations offers business opportunities for facility owners and real estate owners to act as local operators that offer coverage and capacity to businesses and mobile operators. The secondary use of spectrum (or use of unlicensed bands) enables local operators to act more freely, exploiting the control of the local environment. The business models for shared indoor infrastructure enable facility owners to play a key role. The secondary use of spectrum for indoor systems also has a number of technical benefits. It enables off-loading of heavy data traffic from the macrocell systems, offers capacity without using operator spectrum and it reduces interference problems.

3. The analysis shows that existing operators are in a good position for making cost-efficient use of secondary access to spectrum since they can re-use existing infrastructure. The TV white space can be used as a complementary resource, the basic (and reliable) resource is provided by licensed spectrum.

4. Existing actors with ongoing business are in a better position than new competing actors that need to enter the market, make investments and build up infrastructure, service offers, customer base, brand etc. Hence, it would be interesting to analyze additional business cases where established actors make use of secondary access of spectrum in order to offer new services. One example is broadcasting companies that can offer mobile broadband access. Here there would be room for close coordination of the broadcasting and mobile broadband access systems.

Form the analysis we can identify some implications for the further analysis of business cases. With our analysis approach it is obvious that market entrants will be in a more difficult position than established actors. New operators need to invest in networks, platforms, marketing, customers, etc. Hence this economic problem shift from being an issue related to cost for cognitive radio to be a general problem about market entry.

Cognitive radio is often discussed in terms of new actors and new types of actors that start to offer new services (to new customers). If actors, services, markets etc are all "new" this will be a substantial problem for the adoption of services based on secondary access of spectrum and cognitive radio. More attention should be put on existing actors offering "new services to existing customers" or improving cost-efficiency of existing services.

# 4 Business Analysis of Rural Broadband provisioning with TVWS: Fixed-line operator perspective

In this chapter, we quantitatively investigate the feasibility of rural broadband provisioning TV white spaces from the perspective of a fixed line operator. We consider a hybrid architecture where wireless broadband to rural houses is provided using point-to-multipoint white space links at the end of the existing fixed-line infrastructure connectivity points, such as an exchange or a cabinet. The techno-economic study results show that it is a technically and commercially feasible solution. This is because the proposed solution not only eliminates the cost of the spectrum, by using white spaces, but also other dominant costs, i.e. site procurement/build and backhaul can be greatly reduced by reusing existing infrastructure and backhaul available to operator.

## 4.1 Background

Significant numbers of rural premises often in difficult terrain are too far from a cellular base station or a fixed-line exchange to obtain a decent broadband data-rate. Along with greater distances, lack of critical population to warrant sufficient investment in infrastructure is the primary reason for rural premises to be either underserved or un-served. We refer to such customer premises as 'broadband not-spots' or simply 'not-spots'. In the United Kingdom, there are an estimated 2.6 million not-spots [ICT-KTN], the majority of which (but not all) are in rural areas. The "not-spot" problem and the resulting "digital divide" between urban and rural populations is not limited to the UK but is also a major issue in other developed countries such as the United States and Canada, where a large fraction of the population lives in rural communities; recent statistics indicate that about 30 percent of the rural population in the European Union (EU) has no access to high speed Internet.

Governments and regulators are taking various measures to address this problem. In the UK, under the Digital Britain [DIGI] program, the UK government has set a Universal Service Obligation (USO) for operators to provide 2 Mbps data-link during the busiest 3 hours daily period to over 95% of UK premises by 2016. Further, UK communication regulator Ofcom have set a rural coverage criterion for the cellular operators bidding for a national 800MHz spectrum license i.e., the license bidder would have serve an area in which 95% of the population lives, providing a sustained downlink speed of 2Mbps with a 90% probability of indoor reception by the end of 2017 [OFCOM-LTE].

Cellular network operating costs are currently such that it may be challenging for cellular operators to use traditional macro network designs to provide the same level of coverage/capacity for rural population even with LTE technology. This is mainly because of an increase in the number of base stations that would be required due to the range reduction associated with minimum data-rate criteria of 2Mb/s and limited spectrum availability in the recently cleared 800MHz band (2x10MHz per operator in the UK). Significant investments would have to be made for both acquiring new sites and providing the additional higher capacity backhaul. This along with the anticipated high spectrum costs of the 800MHz[8] licence suggests the business case for rural broadband with cellular networks may appears economically unviable [ICT-KTN].

The Wireless Internet Service Provider (WISP) community in the United States has attempted to solve the rural broadband problem with the use of license-exempt ISM bands at various frequencies. The advantage of using ISM bands is that there are no licence costs, a low cost base and plenty of spectrum availability, for example the 5GHz ISM has about 19, 20MHz channels while the 2.4GHz band has about 83MHz of

[8] The UK spectrum auction of 800MHz licence due later in 2012 is tied with the rural capacity/coverage obligation; based on an equivalent German auction price of £0.600/MHz/population for the UK, this equates to about £744m in the UK for 2x10MHz for a population of 62 million.

spectrum. Unfortunately the high spectrum availability is not in the right frequency range. Due to propagation losses in higher frequency bands and a regulated EIRP ceiling limit of 20dBm in 2.4GHz and 30dBm in 5GHz in the UK and the rest of the Europe, the link budget is unable to achieve the required range for a viable rural broadband service. Further, due to the significant site acquisition/installation costs along with the backhaul costs have resulted in a limited success of this approach.

In [SICK] the authors examine the use of cognitive radio technology and white spaces for broadband wireless access in urban and rural regions under various licensing models. The study findings recommend use of white spaces with a license-exempt model in rural areas. The work presented in [MGSM11] assesses the business feasibility analysis of cellular use of TV White Spaces (TVWS). Paper [Marcas12] performs a similar business feasibility study of providing mobile broadband access using TVWS for two actors namely incumbent and Greenfield. It concludes that due to high infrastructure and transmissions costs it would be challenging for new entrants to provide such a service.

In this chapter, we quantitatively investigate techno-economical feasibility of rural broadband provisioning TV white spaces from the *perspective of a fixed line operator.* Examples of UK demographics and the UK's fixed-line operator BT, are used as a concrete example, but a similar modelling and analysis could be extended to other countries facing a similar problems and opportunities. TV White Spaces offers a potential opportunity as large portions of VHF/UHF TV bands have become available for cognitive access in the United States and are expected to become available in the UK in the 2012-2013 timescale [FCC-2011, OFCOM-1, and NEKOVEE]. This is due to the improved propagation characteristics when operating at low frequencies and due to large white space spectrum availability in remote rural areas. Additionally, TVWS proposition is an attractive as the spectrum is effectively free to secondary users provided they do not interfere with the primary network. Consequently service providers are looking into wireless alternatives using TVWS.

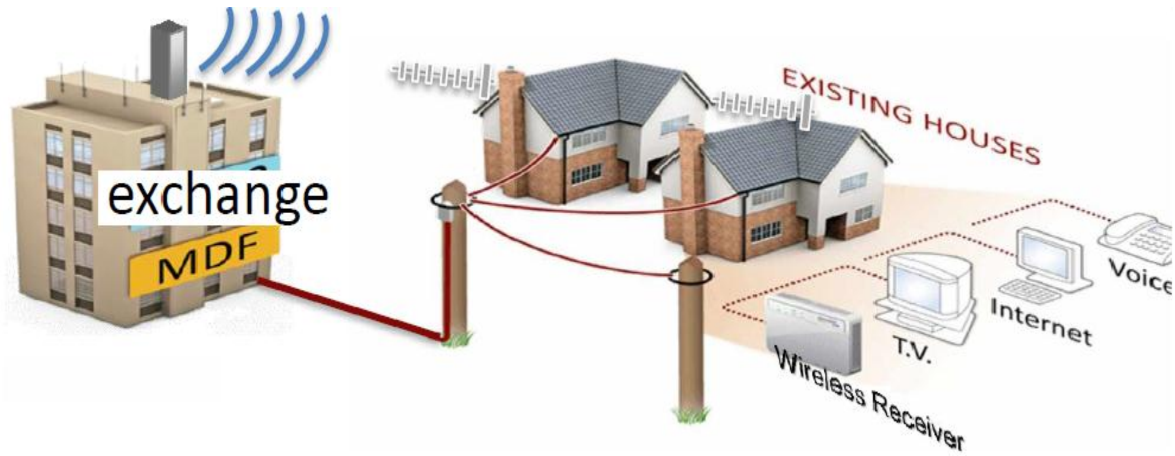



Fig 4-1: Network topology for rural broadband connectivity, a TVWS base station located on top of an exchange building of a fixed line operator.

## 4.2 Technical Study Results

The network topology proposed is essentially a point-to-point or point-to-multipoint wireless system with a TVWS base station mounted on top of incumbents exchange or a cabinet and external antenna on client roof-tops as illustrated in Figure 4-1 The TVWS base station is assumed to be registered with an authorized geo-location database provider, which provides it with information on the available TVWS channels within its coverage area as well additional parameters, such as maximum permissible EIRP to be used in each channel. The TVWS equipment at the client's end is professionally installed and operates in master-slave mode under the command of the base station. Finally, connectivity inside premises could be distributed to end-user devices using a fixed connection, or wirelessly, e.g. via a WiFi link. To assess the technical feasibility of the proposal, we have developed a set of modelling/simulation tools that are run over a series of scenarios as explained below.

### 4.2.1 Quantifying Rural Not-Spots

The aim of this section is to understand the distribution statistics of the not-spots with respect to fixed-line infrastructure connectivity and further quantify the total number of rural not-spots. Figure 4-2 provides the distribution statistics of not-spot distance to its nearest exchange. As seen from the figure about 95% of the rural not-spots are within 6km radius from a fixed-line exchange. Premises on the left-end of the PDF i.e., those with the line length less than about 3 km are not considered for TVWS solution as they would be soon served with an on-going deeper rollout of fixed-line connectivity. Premises on the right-end of the spectrum i.e. a small percentage of premises with a line-length beyond 6km would be probably addressed by Satellite technology. They are not considered for a TVWS solution due to the limited EIRP available to the secondary TVWS system due to protection requirement of primary network Digital Terrestrial Network (DTT) reception[9]. The window of opportunity identified for TVWS solution is premises which are in between 3 km and 6 km from an exchange or cabinet location; this turns out to be approximately close to a million.

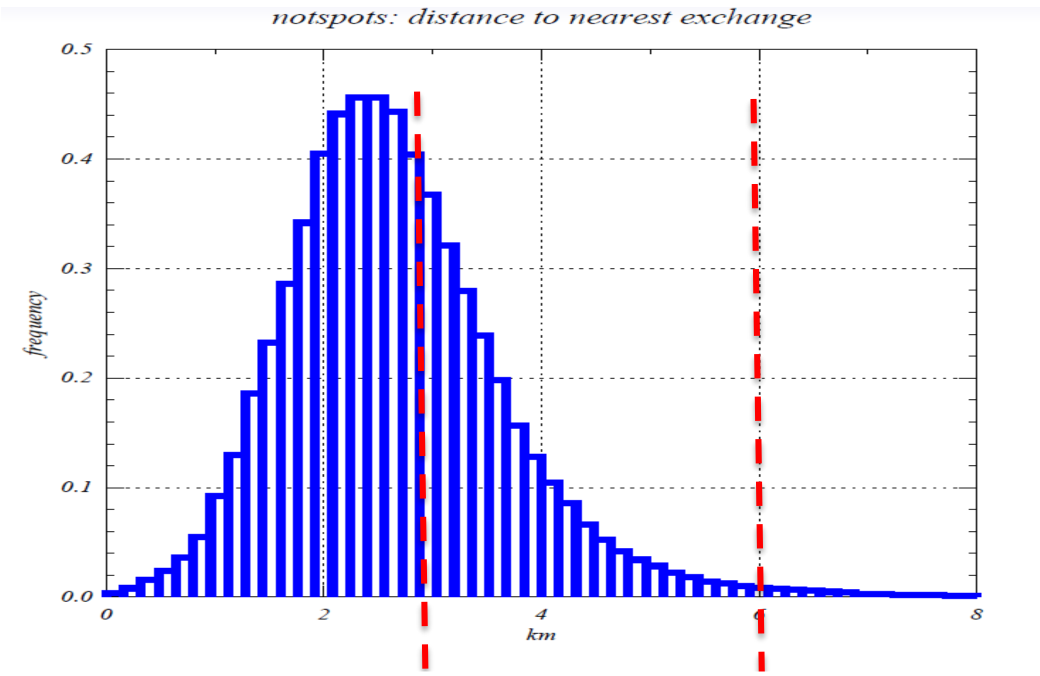


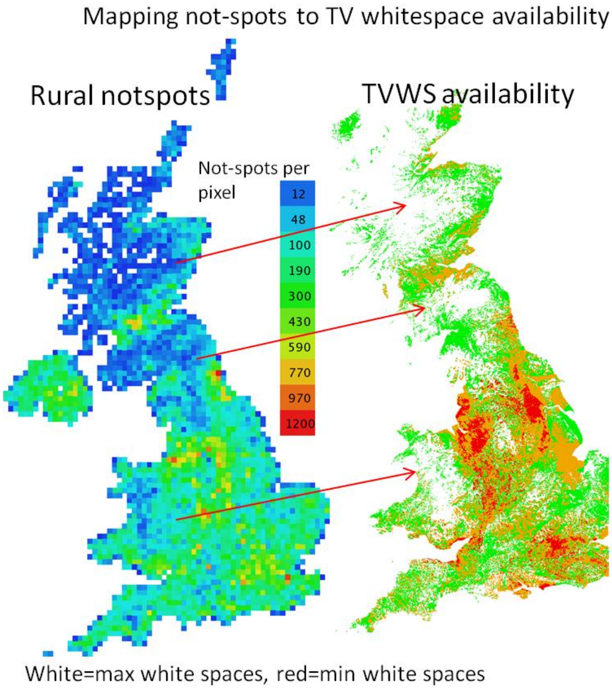

Fig 4-2: Distribution statistics of rural not-spots to the nearest exchange, 95% not-spots within 6km radius , window of opportunity from 3km to 6km

[9] This is in consideration of Ofcom unlike the FCC not imposing a maximum transmit power limit on devices that rely on a geo-location database for incumbent protection but leaving it to be determined by the database.

### 4.2.2 TV White Spaces spectrum availability

Next we investigate the TV white space spectrum availability as a function of transmit power for rural regions. Not-spots in rural areas generally tend to be clustered into groups, with typical density being 10 to 30. Each isolated rural community is characterized by two parameters; the number of not-spots in the cluster and the distance between the furthermost not-spot and the nearest exchange. The first parameter determines the required wireless channel bandwidth that needs to be available in order to provide required 2 Mb/s broadband to premises while the maximum distance determines the associated transmit power level required to establish the required connectivity link. The spectrum availability and variations of TV white spaces spectrum across the UK is modelled using publicly available coverage maps of DTT network generated via computer simulations, Ofcom's database of transmitter and repeater location, transmit power, antenna height, frequencies, etc. Combining the TV field strength data with propagation modelling, the available TVWS spectrum for secondary use of spectrum in a given rural location is computed with a spatial resolution of 100m. Figure 4-3 a shows mapping of identified rural not-spots in the previous sub-section study to TVWS spectrum availability.

The figure shows an excellent mapping of the not-spots with TV white space availability i.e. high spectrum availability for rural regions such as Scotland and Wales. Figure 4.3b provides quantitative results of the population-weighted TVWS availability as a complementary cumulative distribution function (CCDF) for the rural UK. The green curve in figure shows the CCDF with the Adjacent Channel Constraint (ACC) while the red curve shows the availability without ACC. With ACC restriction, a channel adjacent to a TV channel is not available to secondary system due to transmit and receive filters imperfections. As can be seen from figure even with the ACC, a large number of TV channels are available for rural UK population, e.g. about 90% have access to at least 3 contiguous channels. Overall, high spectrum availability in lower frequency band with sufficient power levels enables an adequate link-budget required for the rural broadband service. In this study we assume availability of a minimum of 3 TVWS channels with a maximum EIRP of 4W to the service provider deploying rural broadband service.



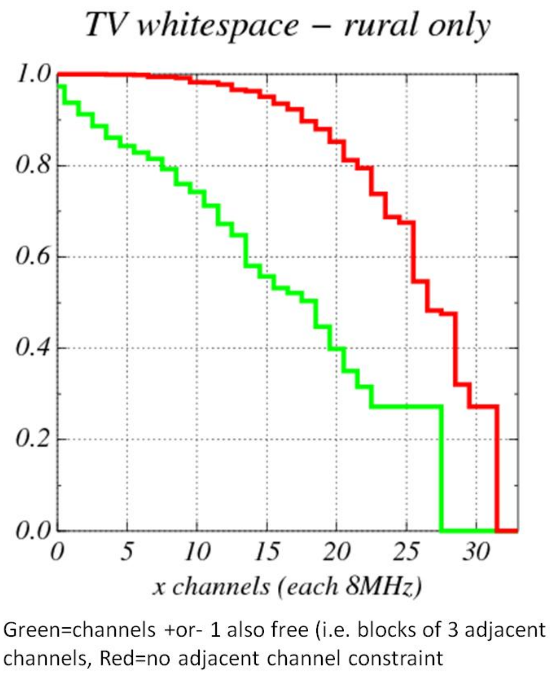




Fig 4-3a: Mapping Not-spots to TVWS availability, Fig 4-3b: TVWS spectrum availability for rural UK

#### 4.2.3 Mapping Not-Spots to exchange/cabinet locations

Next, we map and evaluate the percentage of identified rural not-spots that could be covered when TVWS base stations are installed at selected exchange and cabinet locations. The problem is approached in terms of estimating the number of TVWS base stations required to provide the rural capacity/coverage criteria. This exercise makes use of some proprietary data regarding infrastructure locations, the location of the not-spots, and UK's database of houses.

The white space technology selected for study is TDD-LTE. Since TVWS is technology agnostic other air interface like IEEE 802.22 specifically designed for rural/regional access and ratified July 2011, WiMAX or customized WiFi are acceptable. Firstly, the LTE sector capacity is calculated for given link-budget parameters; these include an EIRP of 36dBm per TVWS channel, receive antenna gain of 7dBi, transmit antenna height of 12m, outdoor roof-top reception. Receiver antenna height 5m, total channel bandwidth for downlink to be 15MHz i.e. 5MHz of each white space channel with an appropriate downlink-to-uplink ratio, downlink study only, noise figure of 8dB, receiver implementation margin 3dB and an uniform distribution. With these assumptions, results are shown in Table 4-1, the average LTE sector capacity dimensioned with a cell radius of about 6km turns out be about 14Mb/s.

Table 4-1: LTE sector capacity calculations for a 15MHz D/L channel

| Modulation & Coding levels | Effective data rate with 25% link layer overheads (Mb/s) | Required SNR (dB) | Typical LTE Link Budget (dB) | Max Possible Range (km) | Max coverage (sq km) | Fraction of users/data-rate |
|---|---|---|---|---|---|---|
| 1/2 QPSK | 8.70 | 5.05 | 130.17 | 6.48 | 84.03 | 0.61 |
| 3/4 QPSK | 13.04 | 10.31 | 124.91 | 4.07 | 33.10 | 0.03 |
| 1/2 16-QAM | 17.39 | 10.83 | 124.39 | 3.89 | 30.19 | 0.22 |
| 3/4 16-QAM | 26.09 | 16.03 | 119.19 | 2.45 | 12.02 | 0.02 |
| 1/2 64-QAM | 26.09 | 16.7 | 118.52 | 2.31 | 10.67 | 0.07 |
| 2/3 64-QAM | 34.79 | 21.29 | 113.93 | 1.54 | 4.73 | 0.01 |
| 3/4 64-QAM | 39.13 | 22.24 | 112.98 | 1.41 | 4.00 | 0.01 |
| 5/6 64-QAM | 43.48 | 23.86 | 111.36 | 1.23 | 3.00 | 0.04 |
| | | | | Avg. data rate per sector 14.1Mbps | | |

Next, the total number of TVWS base stations required to meet the rural coverage/capacity requirement is calculated. As an approximation all the fragmented rural areas are aggregated as one area and the number of base stations needed to serve the entire area is calculated. This simplification results in certain errors related to cell-edge effects of each rural region, which we believe are not significant in order of magnitude. However, a more detailed study is required to estimate these errors. The network dimensioning assumed applies a contention ratio of 20:1; this translates to a data-rate of 100Kbps simultaneous access during the busy hour. Contended radio interface has finite capacity and impact on user experience. A higher contention ratio could be considered but this would degrade the quality of broadband experience and would not be a fair comparison with fixed-line broadband service which uses similar contention ratios for network dimensioning. Table 4-2 presents the number of base stations needed to cover certain percentage of rural not-spots market. It can be seen that for the assumptions made just fewer than 10,000 base stations are required to meet the requirement.

Table 4-2: No of TVWS base stations needed for to provide guaranteed 100Kb/s RBB service (20:1 contention ratio for a 2MB/s EoC), 3 sectors per BS.

| **% of rural not-spots covered** | 20% | 40% | 60% | 80% | 100% |
|---|---|---|---|---|---|
| **No of TVWS Base stations needed** | 1900 | 3800 | 5700 | 7500 | 9500 |

### 4.2.4 Service protection with Soft-Licence

Service providers planning to deploy the rural broadband service in license-exempt (LE) White Spaces require sustained access to spectrum which is predictable and measurable. This is essential to offer certainty of the offered service with respect to service availability and quality. With the emergence of geolocation databases as the regulators' preferred approach to incumbent protection, mechanisms to ascertain the availability and quality of the TVWS spectrum are becoming available. This approach can largely eliminate the fundamental uncertainty associated with a sensing-based approach to TVWS access.

However, under the licence-exempt spectrum management model currently adopted by both the FCC and Ofcom, there is nothing that prevents secondary white space infrastructure being deployed by different operators in same location and same channel. As the rural broadband service has a larger coverage range the probability of capturing contending users and interference goes up as a function of coverage area unlike the typical short-range conventional WiFi systems. The license-exempt model may become increasingly problematic as usage volumes increase because the associated delay variability would eventually become unacceptable for typical rural broadband usage. To address the service protection problem, a novel light-touch regulatory model called 'Soft-Licence' is proposed in [KAWAD]. A brief summary is provided here as illustrated with Figure 4-4.

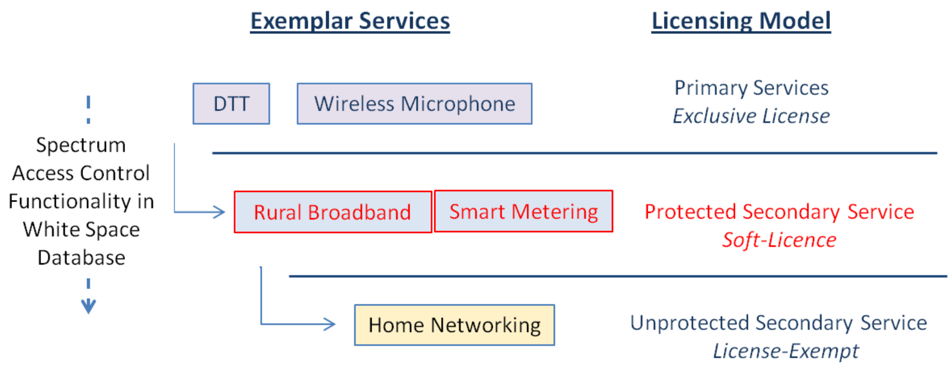



Fig 4-4: Protection of rural broadband service with Soft-Licence & Protected Service Category

Currently in the TVWS context there are two service categories identified, the 'Primary Service' category which comprises the DTT and wireless microphone service and the 'License-Exempt Service' category. A new intermediate service category called 'Protected Secondary Service' category is introduced. Rural broadband service is tagged as a Protected Secondary Service by the regulator in the geolocation white space database and protection is granted with Soft-Licence concept. The geolocation white space spectrum access control functionality is extended to ensure both the Primary and Protected Secondary Services are protected from the license-exempt service category i.e., all license-exempt services in the coverage area of a Protected Secondary would have to operate at a power level determined by certain interference protection ratio i.e., no higher than some specified value below that used by the Protected Secondary Service.

Soft-Licence is a novel flexible licensing mode that sits between the exclusive license and license-exempt model. It is a pseudo license category i.e., when viewed by license-exempt service it makes the Protected Service appear as a Primary Service while when viewed from a Primary Service perspective it makes the Protected Service appear as any license-exempt system. It should be noted that the Primary Service could cause service disruption to the Protected Secondary Service as protection is offered only from license-exempt users. This constraint would change on relatively slow time-scales due to changing Primary user requirements / usage. Further there is an element of statistics regarding spectrum availability as to whether or not a Protected Service Category can be accommodated in the same coverage area. Consequently, it follows that obtaining a Soft-Licence will probably require the Protected Secondary provider to enter into negotiations with the regulators. Examples of how the constraints would shape the Soft-Licence would be - limited licence for certain rural/regional geo-types is issued; different frequency channels in different regions/times but a certain bandwidth is reserved or the license duration being shorter unlike an exclusive licence.

## 4.3 High-level Economic Analysis

This section presents an initial economic analysis of the Fixed-line operator scenario using the TVWS proposal. Based on the technical study we estimate the number of TVWS base stations required to offer rural broadband service to be around 10k. Assuming an equipment and installation cost of £20k per base station, total costs on the base station side would be about £200m with another £5m for the geolocation database build. A rough estimate of the total CAPEX on base station side is £205m. Client side costs are treated on a yearly up-take basis, unlike the base station side which will be an upfront start-up cost. Figure 4-5 provides an income statement forecasts in pictorial form with the various revenue and cost assumptions: time window assumed 5 years, a yearly uptake of 20% subscribers; £40 monthly subscription fee per premise; tax and inflation ignored; client equipment & installation cost of £300 per premise, client side maintenance cost of £50 per premise, base station site rental and maintenance costs of £2k per site, backhaul and ISP costs of £10k per site, geolocation database maintenance support of £5m per annum and a 20% depreciation costs of base station equipment.

As seen from the figure this is a positive business case with the year to break-even being year 3. The economic analysis could be easily extended to the forecast the incremental cash flow and generate the net present value (NPV) and internal rate of return (IRR) for the investment. For example, assuming a cash of capital of 8% and a working capital of 0% gives a positive NPV of about £33m and an IRR of 11%. Based on the economic analysis, multiple physical networks for rural broadband using with white spaces appear to be economically unviable. Deep sharing and integration of network resources is recommended. This could potentially lead to a single consolidated physical network operated on wholesale basis in rural environments with all other operators

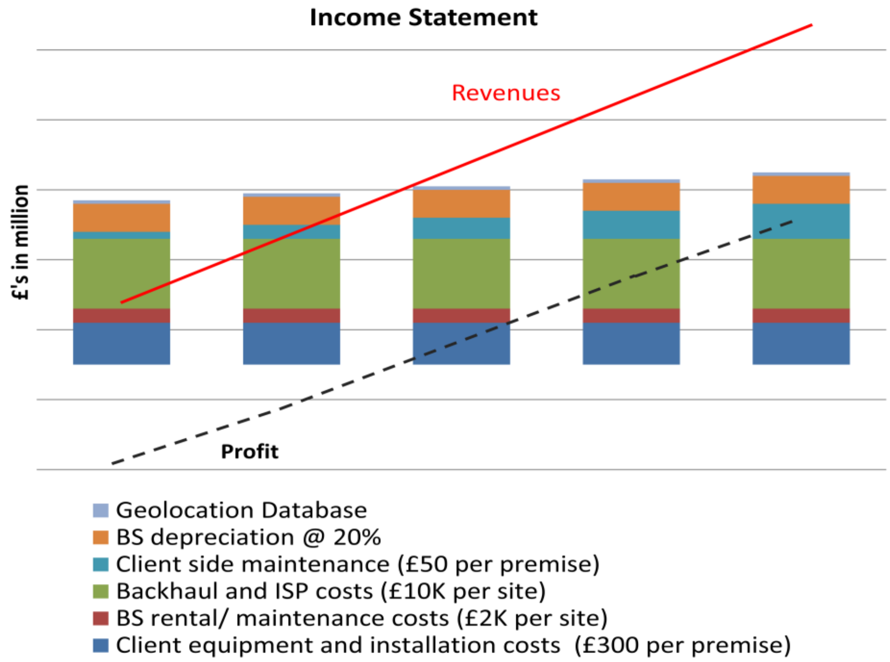



Figure 4-5: Income Statement Forecasts

becoming virtual network operators or service retailers.

## 4.4 Comparison with other Rural Broadband provisioning approaches

The below table provides a high level comparison of the various approaches to provide rural broadband service based on actual UK players and demographics as opposed to hypothetical assumptions. The three actors are

- The Fixed-line op:WS the case studied in this chapter; For example BT in the UK intending to use white spaces[10]
- Existing MNO:Licensed being where existing cellular operators use LTE technology in the 800MHz licensed band to provide the service;
- TVWS: WS is the new entrant building a rural broadband network with TV white spaces, for example this company Neul[11] in the UK

Table 4-3: CAPEX comparison of the various proposals

| Case | DL Band-width | No new sites | cost per site | Total site costs | Spectrum costs | Total CAPEX |
|---|---|---|---|---|---|---|
| Fixed line op: WS | 15 MHz | 10000 | £20k | £200m | £5m for the database | £205m |
| Existing MNO: Licensed (800MHz licensed band with LTE) | 10 MHz | 12000 (Based on an internal BT study) | £100k (Based on various market estimates ) | £1.2b | £35m | £1.23b |
| Existing MNO_Sharing: Licensed: With 3 operators sharing n/w infrastructure, cost per operator is | 30MHz | 4000 | £100k | £400m | £35m | £435m |
| New TVWS:WS | 15MHz | 10000 | £80k | £800m | - | £800m |

The findings in table suggest that in the case of the UK the 'Fixed-line op:WS' case is the most cost effective approach to build this network; followed by the 'MNO_Sharing:Licensed' case with network sharing, followed by the new 'TVWS:WS' option.

The 'MNO:Licensed' case without sharing has the most dominant costs primarily due to (a) site and equipment costs for additional base stations needed and (b) the spectrum costs. This is elaborated below:

Spectrum price in licensed band in each country is affected by a number of factors such as regulatory rules related to coverage obligation, spectrum ceilings, new entrants package, license durations and also based on economic conditions such as level of competition, affluence of the country, etc. The UK spectrum auction of 800MHz and 2.6GHz frequencies will be held later 2012, so we estimate the spectrum price based on German auctions as an approximation. Using the reference of German 800MHz auction

[10] http://www.btplc.com/ngb/News/IsleofBute.htm
[11] http://www.neul.com/markets.php

prices i.e. £0.600/MHz/population; spectrum prices are given as normalised figures i.e. price/MHz/Population. This equates to about £744m in the UK for 2x10MHz in the 800MHz band for a population base of 62 million. It is common for several cellular propositions to be summed in order to build an overall business case so items like spectrum costs are shared. It should be noted that since the 800MHz spectrum would be used in urban areas as well, the £744m spectrum costs reflects the operator's wider business interests. So if the rural broadband business case is treated as one of the propositions by the cellular operator, the value of the spectrum is £35m assuming a rural population base of 3m in the UK instead of the national population of 62m. We use this figure as the value of the licensed spectrum for the RBB service though the price to be paid would still be £744m on national basis.

A significant reduction could be achieved if cellular operators decide to share their network costs as seen in the tabular results for the 'MNO_Sharing:Licensed' case. This is due to cost-savings on the site acquisition/build/install and backhaul provisioning which account for about 70% of the new build site costs. One suggestion is to opt for a full sharing/integration of cellular network and infrastructure resources leading to single consolidated physical network that is operated on Wholesale basis in rural environments[12]. Competition could be unaffected as other cellular operators would operate as MVNO service retailers. .

Finally with the new 'TVWS:WS' case, using a typical split of CAPEX of site acquisition, construction and install being ~60%, equipment costs being ~30% and backhaul provisioning the remaining ~10% cost for a new build site, we estimate the cost per site would be around £80k. However unlike the networking sharing concept in the 'MNO_Sharing:Licensed' case or unlike the reuse of existing site locations and power/backhaul availability in the 'Fixed-line op:WS' case, there is no option to reduce this CAPEX further. Based on the findings we could also conclude that a nationwide service provision of a rural broadband network by a new entrant may not be viable hence not recommended.

[12] http://www.mobilebusinessbriefing.com/articles/o2-and-vodafone-up-the-stakes-in-uk-4g-race-via-new-network-sharing-deal/24139

## 4.5 Conclusion

We proposed an alternative approach of providing rural broadband service with a TV white space base station installed on fixed-line exchange and cabinets and an external roof-top antenna on a client premise.  In our technical study we quantify the UK rural not-spots market and compute the TV white space spectrum and power availability for rural regions. This incorporates real white space availability; population density and the location of exchanges. Then, we determine the number of TV white space base stations required at end of existing fixed-line infrastructure to serve rural not-spots followed by a high-level economic analysis with costs related to infrastructure, backhaul, sites, etc, which were often overlooked in previous studies.

Overall, based on the techno-economic analysis, we conclude that the proposed approach offers an excellent opportunity to solve the rural broadband problem. Our proposal eliminates the dominant costs of network deployment and significantly brings down the CAPEX and OPEX (a) associated spectrum costs as TVWS are effectively free (b) investments needed for new infrastructure/sites with reuse of existing fixed-line infrastructure (c) investments needed backhaul and power provisioning with use of existing exchange and cabinet locations.

However certain challenges with TV white space approach were identified. The rural broadband service in license-exempt TV white spaces would need some form of interference protection from other secondary services. This is addressed with the Soft-Licence proposal which provides the certainty needed by service providers to deploy infrastructure based on spectrum shared amongst multiple systems. Secondly, since the rural broadband service is required to protect the primary network, this introduces an EIRP/link-budget constraint when operating on outdoor settings with elevated antenna heights. To achieve the required link budget, an external roof-top at client side becomes essential which incurs significant costs. Finally, a sufficient TV white space spectrum availability (3 channels at 4W used in our study) is essential. If the primary protection margins were to be overly restrictive resulting in lower white space availability, the number of TV white space base stations then required would go up.

Finally we perform a high level economic comparison of our proposal to a MNO using licensed 800MHz spectrum and a new entrant player using TVWS.  Results indicate a deep infrastructure network sharing for the MNO is mandatory to may their economic case viable; this is true for the fixed-line with white spaces proposal as well; The case looks negative for a new entrant player due to high network build CAPEX hence is not recommended.

# 5 Business analysis of macro cellular use of TV white spaces

In this chapter we discuss the situation where an existing cellular operator either wants to deploy a new macro cellular LTE network using licensed spectrum (referred to as a standalone network) or to enhance the capacity of an existing macro cellular LTE network using secondary access of TVWS spectrum (referred to as a DSA enabled network). This analysis complements the findings in chapter three where we investigated the situation where more licensed spectrum is not an option.

We investigate the business value of for the operator to do so in various ways: The operator may either invest in equipment for TVWS usage or to upgrade the network using licensed dedicated spectrum that would provide the same capacity as the TVWS opportunities. We assume that the TVWS usage is license-exempt and that the cellular system must share the available capacity with an unknown number of systems. The main question addressed in this section is what option would be more beneficial to the operator. To this end we investigate the business viability of the following scenarios:

- A standalone macro cellular network using TVWS opportunities to provide coverage. In this case the TVWS opportunities are the only spectrum resources available to the operator.
- A standalone macro cellular network using licensed spectrum to realize the same capacity and coverage as in the previous case, i.e., the operator does not have access to more licensed spectrum than the amount required to provide the same service as if operating in TVWS.
- A DSA enabled network using TVWS opportunities to enhance capacity. The operator is here assumed to have access to licensed spectrum in addition to the TVWS opportunities, and that this licensed spectrum is used to provide a basic service, e.g., coverage, to end customers.
- A DSA enabled network using licensed spectrum to realize the same capacity as in the previous case, i.e., to realize the same capacity that is possible when using TVWS opportunities. Here it is assumed, as in the previous case, that the operator also has access to additional licensed spectrum that it uses to provide a basic service, e.g., coverage.

An analysis of the available capacity to an operator using TVWS opportunities for a standalone or DSA enabled macro-cellular network has been investigated in section 2.1 of [D5.3] and the present study extends those results to make statements about which scenarios may be preferable from a business perspective.

To limit the uncertainties in the estimates and the models the main results will be comparisons and statements on what business option is more beneficial, given the models and parameters. We also present a sensitivity analysis varying the relevant parameters and investigate the robustness of the conclusion to these variations.

To be able to compare two spectrum use cases, using licensed dedicated spectrum and using TVWS opportunities, we define the *equivalent bandwidth of licensed dedicated spectrum* as the bandwidth in dedicated spectrum needed to provide the same capacity as may be provided in the same location by using TVWS opportunities. The capacity[13] provided by TVWS in Germany for a DSA enabled network and the corresponding equivalent bandwidth is shown in Figure 5-1 below, cf. section 0 for more details. Here we assume that the licensed dedicated spectrum is reserved for usage by only the license holder, but the amount of spectrum needed depends on the regulation of the TVWS, which is here assumed to be license-exempt.

[13] In this entire section 'capacity' refers to the long term average sum cell throughput of an LTE cell using all of the available and useful TVWS channels.

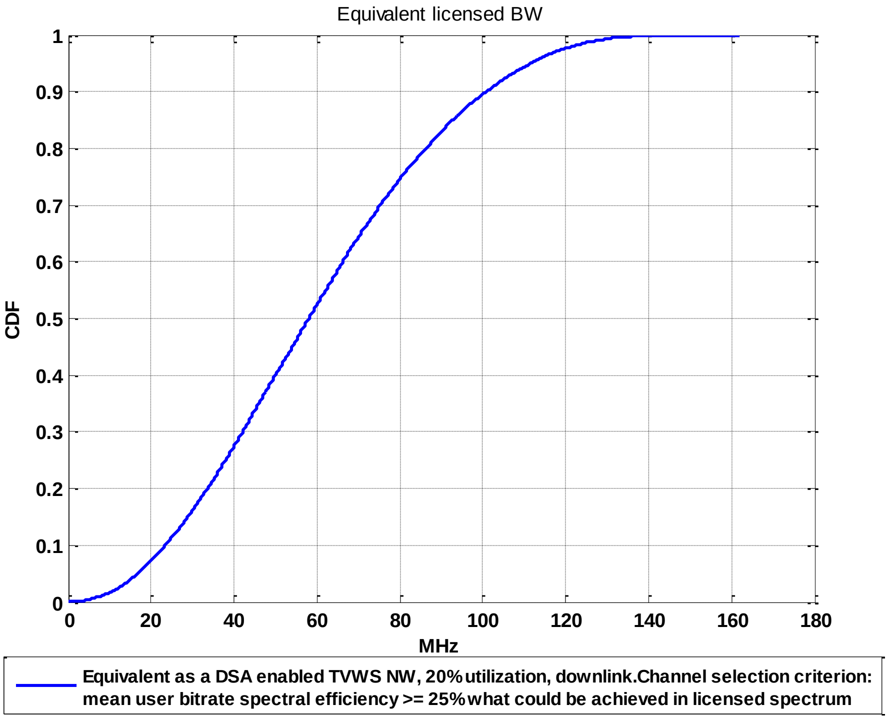



Figure 5-1: Bandwidth needed for an operator to provide the same capacity in licensed spectrum with a spectral efficiency of 1bits/s/Hz as could be provided in TVWS. The CDF is taken over all locations in Germany. Same data as in section 2.1 of [D5.3] is used.

It should be noted that for more than 90% of German locations it would require more than 20 MHz bandwidth to get the same capacity as TVWS if the spectral efficiency in licensed bands is assumed to be 1 bit/s/Hz. However, if a service with a factor higher spectral efficiency is used the equivalent dedicated bandwidth will scale down by the same factor.

In this study we consider only the downlink capacity of the TVWS usage. This since the main focus of this study will be on boosting capacity of a cellular network and then the downlink is most often considered as usable [D5.3]. This is also motivated by the conclusion in section 2.1 of [D5.3] that the uplink shows less potential since receiver antennas are more exposed to interfering TV signals than in the downlink.

## 5.1 Utility function for comparing business cases

To enable a comparison between the spectrum use cases (using licensed dedicated spectrum or TVWS opportunities) for the two different deployment options for an operator we would estimate the net present value (NPV) of the cash flows related to the cellular network. For this we define a utility as the difference of the net present values of revenue and operating expenditures (OPEX) plus capital expenditures (CAPEX):

$$\text{Utility}_{\text{NPV}} = \text{Revenue}_{\text{NPV}} - \text{OPEX}_{\text{NPV}} - \text{CAPEX}$$

Whenever this utility NPV is positive the studied scenario has a positive business case and hence the investment will add value to the operator. On the other hand if it is negative it is not advisable to go into the business, doing so will not be profitable for the operator.

To limit the impact of possible errors in various parameters we will use the utility to study differences between different scenarios, and in this respect use it as a mean to find the preferred business case. In particular we will use it to shine some light on the question of which business case is the most beneficial to provide the same service; cellular TVWS usage or using an equivalent bandwidth in dedicated spectrum.

To decide which business case is preferable we thus compare the utilities for the different scenarios and use cases. According to the above definition of equivalent bandwidth of licensed dedicated spectrum we may assume that in both the situation where an operator uses TVWS opportunities and the situation where the operator licenses an equivalent bandwidth of dedicated spectrum the compare the cases where the revenue, OPEX are the same. Thus comparing the business cases boils down to comparing the CAPEX.

TVWS scenarios have CAPEX coming from investments in deploying sites and from the TVWS database fee per subscriber device (WSD) whereas the licensed spectrum case has CAPEX coming from site deployment costs and the upfront investment in licensing the spectrum.

In the following subsections the various aspects of the used CAPEX model are introduced.

The CAPEX of the operator comprise upfront investments in equipment needed to provide cellular services in the band under consideration, i.e., TVWS or dedicated spectrum. If the TVWS usage scenarios are investigated a one time cost per WSD for accessing a TVWS geo-location database is included in CAPEX. On the other hand for cases where the operator wants to use an equivalent bandwidth of dedicated spectrum there is a cost associated with licensing this bandwidth.

### 5.1.1 Cost for upgrading a site

This section relates to the DSA enabled cases, where operators use the capacity provided by the TVWS opportunities to enhance the throughput of an already existing cellular network. The next section will detail costs for rolling out a stand alone network.

To estimate the cost for updating an existing site to be able to use TVWS or extra licensed bandwidth we estimate the number of sites in the considered area by using the population density to map it to an inter-site distance and via the area we get the number of sites. The mapping between population density and ISD used to get the TVWS capacity data in [D5.3] is repeated in Table 5-1.

Table 5-1: Population density to inter-site distance (ISD) mapping. [D5.3]

| Population density [inh./km2] | Inter-site distance [m] |
|---|---|
| >1000 (dense urban) | 400 |
| 500-1000 (urban) | 600 |
| 50-500 (suburban) | 1800 |
| <100 (rural) | 5000 |

The number of sites in an area is found by assuming an hexagonal grid of sites and given by

$$\text{Number of sites in area} = \max\left(1, \frac{\text{Area}}{\text{ISD}^2}\right)$$

This number is rounded to the closest integer and we assume that there is at least one site in each considered area. The cost for upgrading all sites in an area becomes

$$\text{Total site upgrade cost} = \text{Number of sites in area} * \text{Upgrade cost per site}$$

The cost for upgrading an LTE site to 20 MHz in year 2010 was about 30 k€/site [MGSM12]. We use this figure as an estimate of the cost for upgrading a site to support more licensed spectrum.

The cost for upgrading a site to operate in TVWS is likely more expensive than upgrading the site to support more licensed spectrum. This will be true in particular in the initial phase of rolling out TVWS capable devices, when production costs are assumed to be higher due to the market being immature, but as the market matures the cost will likely approach that of upgrading to support more licensed spectrum. According to [MGSM12] the upgrade cost per site to support TVWS may be in the range 30-130 k€. We use 60 k€ as an estimate of this cost, unless we state otherwise.

### 5.1.2 Cost for rolling out a stand alone network

If a new market entrant would invest in rolling out a new cellular network aiming to provide coverage using TVWS the cost associated will be much higher than just upgrading existing sites, as discussed in the previous section.

To estimate this cost we use the values given in [MGSM12] for deploying a new site:

- Cost for new site using licensed spectrum: ~110k€/site
- Cost for new site using TVWS: 100-200k€/site (we use 150 k€/site unless stating otherwise)

The reason for assuming a higher deployment cost for a new site that uses TVWS is the same as when we above considered the site upgrade cost: at present the market for TVWS operation is immature and this will likely incur larger equipment production costs, e.g., to cover investments in research and development of the more complex solutions needed for TVWS operation. In the below analysis we use 150k€/site, i.e., a value in the middle of the in [MGSM12] proposed cost range, as a starting point and when comparing the options of operating in TVWS and operating in licensed spectrum this cost will be varied and it is seen that the conclusions are robust under variations of this cost parameter around this value.

To estimate the total cost for deploying a new network in TVWS or in equivalent amount of licensed spectrum in an area we obtain the number of needed sites in the area in the same way as in section 0, and use the above numbers for deployment cost per site:

$$\text{Total site deployment cost} = \text{Number of sites in area} * \text{Cost for deploying new site}$$

### 5.1.3 Cost for accessing a TVWS data base

To account for the cost of operating a TVWS database, that WSDs may access to get information on what TV channels are available and what the corresponding EIRP limits are, it is assumed that the operator will pay a one time fee for each WSD in the system. It is reasonable to assume that this fee will be proportional to the WSD device cost and will be in the range of 5-10% of that cost, thus we here assume that the cost per WSD associated with this TVWS database access is about 5€/WSD. The total cost for an area is given by

$$\text{TVWS database fee} = \text{Population in area} * \text{Market share} * \text{Cost per WSD}$$

This setup implies that the operator is assumed to subsidise this cost to make TVWS usage more attractive to the end user.

### 5.1.4 Cost for licensed spectrum

Total of the bids for the 800 MHz band was 3,576,475,000 €, we have (as per 2010 census) 81,799,600 people in Germany. 60 MHz were auctioned in the 800 MHz band. [Kro10], [BNetzA10]. This gives a cost of 0.73 € per person and MHz. The situation looks different for other auctioned bands:

- 1800 MHz, 50 MHz auctioned for in total 104,355,000 €, i.e., 0.03 € per person and MHz
- 2.6 GHz paired, 140 MHz auctioned for in total 257,777,000 €, i.e., 0.02 € per person and MHz

The 800 MHz band is closest in frequency to the TV bands of the bands that have been auctioned recently in Germany. The band shows the most similar propagation characteristics as the TV band out of the auctioned bands and is thus likely to be valued similar to bandwidth in the TV-bands. For this reason we use the value of 0.73 € per person and MHz when estimating the cost of acquiring licensed spectrum that would result in the same capacity as if TVWS was used.

Note that this assumption makes the cost be smaller than if the operator, as is more common, would have to license the spectrum throughout the country. However we choose to use this approach since it provides in each considered area (pixel) the same capacity as if TVWS was used and hence the revenues and OPEX will be the same, making the two cases easy to compare.

Thus, the equivalent amount of spectrum is given by:

$$\text{Equivalent licensed BW} = \frac{\text{TVWS capacity} * \text{Sharing factor}}{\text{Licensed spectral efficiency}}$$

Here the TVWS capacity is expressed in GB/month and the licensed spectral efficiency is expressed in GB/month/MHz, e.g., 1bit/s/Hz = 324 GB/month/MHz. Unless otherwise stated, we assume a spectral efficiency of 1 bit/s/Hz in licensed spectrum.

The cost for licensing an equivalent amount of licensed spectrum is estimated using:

$$\text{License cost}_{\text{equivalentBW}} = \text{Spectrum cost}_{\text{per MHz and capita}} * \text{Population} * \text{Equivalent dedicated BW},$$

where ‘population’ refers to the number of inhabitants in the area under consideration.

### 5.1.5 CAPEX

For the case where the operator uses TVWS to provide service the total CAPEX is given by the sum of the site upgrade cost and the one time fee for WSDs to access the TVWS geo-location database:

$$\text{CAPEX}_{\text{TVWS}} = \text{Total site upgrade or deployment cost}_{\text{TVWS}} + \text{TVWS database fee}$$

For the case where the operator provides service over an equivalent amount of licensed spectrum the CAPEX becomes:

$$\text{CAPEX}_{\text{equivalentBW}} = \text{Total site upgrade or deployment cost}_{\text{equivalentBW}} + \text{License cost}_{\text{equivalentBW}}$$

Note that the CAPEX is an upfront investment and hence the value is not discounted in any way to represent a net present value.

The CAPEX for the various cases for an area of 13.6 $km^2$ with 4000 inhabitants is shown in Figure 5-2. The area represents an average area of the data in the present study of Germany. In this case 3 sites are deployed or upgraded. Note that the cost for spectrum.

It is notable that the site upgrade or deployment cost dominates the CAPEX indicating that investing in an equivalent amount of spectrum is comparatively cheap. The cost for licensing the amount of spectrum that can provide the specified traffic volume per month is visible as the slope in the green solid and dashed curves. Note that the relative cheapness of spectrum in this case is due to the assumption that the spectrum can be licensed per area, and the licensing cost is proportional to the number of inhabitants.

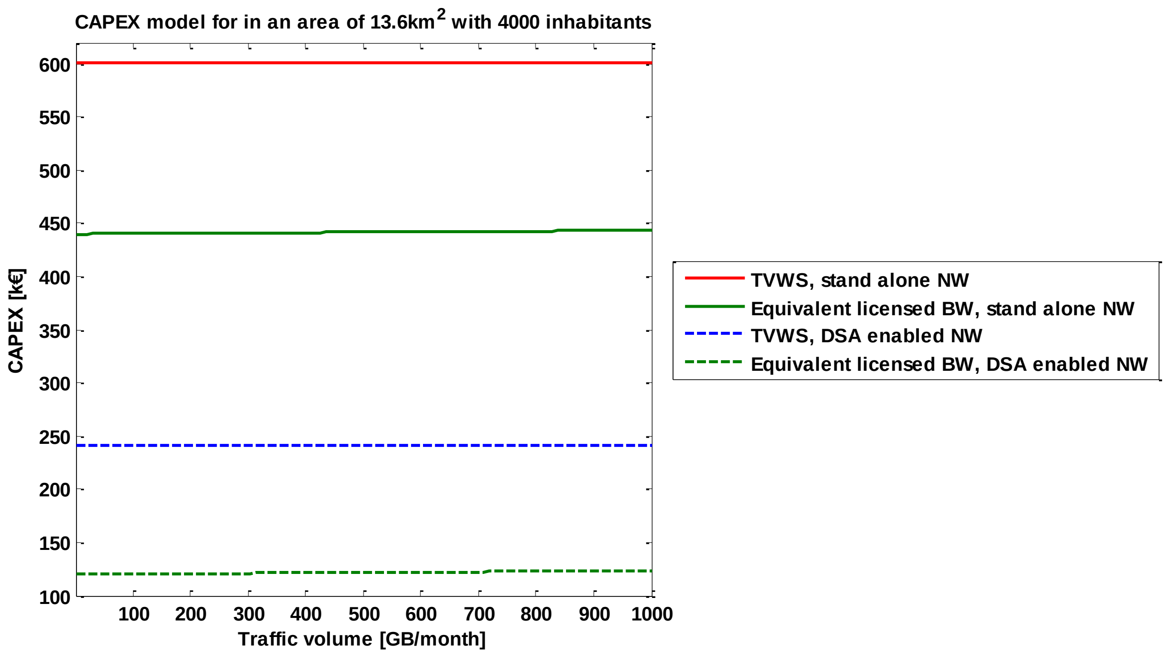



Figure 5-2: CAPEX for an area of 13.6 km² with 4000 inhabitants. The parameters used are specified in Table 5-2.

## 5.2 Numerical results

In all of the numerical evaluations we use the same TVWS capacity data as in section 2.1 of [D5.3]. This capacity data are derived from performance simulations of a macro-cellular LTE network using a subset of the TV channels that are available in each considered area element. The channels composing the subset fulfil a selection criterion reflecting a performance condition set by the operator to make the network reach a particular goal. The rationale for introducing channel selection criteria is that not all, by regulatory rules available TV channels are useful in all circumstances due to potentially large interference levels caused by TV transmissions. For a stand alone network the investigated channel selection conditions ensure that the network may provide coverage over the entire area, while for a DSA enabled network the conditions aim to select channels that are useful to provide a reasonably high performance increase. In the latter case a certain overall spectral efficiency in a cell must be supported by the extension carrier, so that a reasonably large amount of the users in the cell benefits from the additional spectrum.

Apart from respecting the maximal EIRP limits specified in [SE43] for selected each channel the used TV channels that are used are a subset of the channels that are available according to proposed regulation [SE43].

The options for channel selection criteria that are applied to the stand alone network case are:

- If the outage probability (in both uplink and downlink) is smaller than 5% (or 1%), the coverage is considered contiguous and the channel is used. The outage probability is the percentage of the user-bit-rate distribution, which corresponds to 0 bit/s. The bit-rate distribution is the distribution of the achievable bit-rate for users randomly deployed in the system. A TV channel is considered available for cellular network use, if the criterion is met for the minimum required ISD in the corresponding location and under the local circumstances of maximum WSD EIRP limitation and TV interference.
- If the achievable cell edge user-bit-rate is higher than 10 % (or 50 %) of the achievable cell edge user-bit-rate in the interference-limited case, the coverage is

considered contiguous and the channel is used. The interference-limited case is defined as the performance of the LTE system with given ISD with optimally dimensioned BS transmit power.

The options for channel selection criteria for a DSA enabled network are:

- When using TVWS the system's cell spectral efficiency must be at least 25% (or 50%) of the cell spectral efficiency achievable in a LTE system deployed in dedicated spectrum for the channel to be considered as useful.
- If the median of the user-bit-rate distribution is higher than 25% (or 50%) of what can be achieved in the dedicated spectrum reference case the channel is used.

For a more extensive description of the channel selection conditions, see section 2.1 in [D5.3] and [DI12]. Further, the population density data for Germany used in this study has been obtained from [GPW05].

### 5.2.1 Parameter values

The parameter values listed in Table 5-2 are the values used in the numerical evaluations unless otherwise is stated.

Table 5-2: Parameter values used in evaluations

| **Parameter** | **Value** |
|---|---|
| Market share | 30% |
| TVWS opportunity sharing factor | 50% |
| Cost for upgrading a site with TVWS capability | 60 k€ |
| Cost for deploying a new site with TVWS capability | 160 k€ |
| TVWS database access fee | 5 €/WSD |
| Cost for upgrading a site for additional licensed spectrum | 30 k€ |
| Cost for deploying a new site in licensed spectrum | 110 k€ |
| Spectral efficiency using licensed spectrum | 1 bps/s/Hz |
| Price for licensing spectrum | 0.73 €/MHz/capita |

### 5.2.2 Stand-alone macro LTE cellular network

As stated in the introduction a stand-alone network is a network that an operator deploys aiming to provide coverage and mobility. In [D5.3] such a network using only TVWS opportunities was studied and the achievable capacity under different channel selection criteria was found for the German case. The condition to provide coverage conditions is reflected in the channel selection criteria for which TVWS channels to use. In the analysis the operator is assumed to need to completely roll out a new network and hence the deployment cost per site will be higher than for a DSA enabled network, cf. section 0.

A comparison between a using TVWS opportunities and an equivalent amount of licensed bandwidth in dedicated spectrum for a stand-alone network is shown in Figure 5-3.

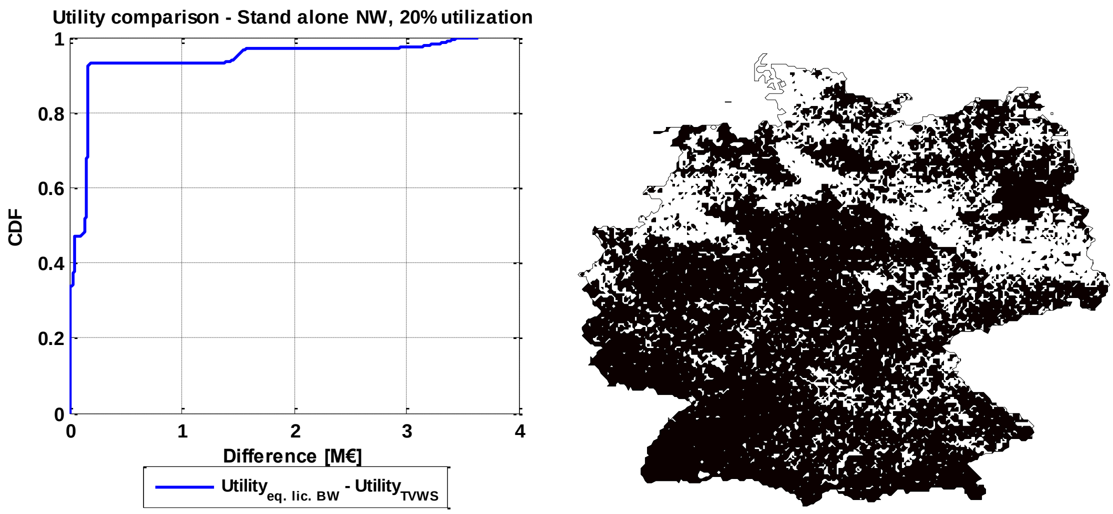



Figure 5-3: CDF (left) of the difference in utility between using equivalent amount of licensed bandwidth and TVWS opportunities for a stand alone network with 20% utilization, and the TVWS channel selection criterion being cell edge bit rate > 10% of the reference performance in dedicated spectrum. The map (right) shows locations (black) where using equivalent amount of dedicated spectrum is preferable to using TVWS, the utility difference > 0.

The utility for operating in an equivalent bandwidth of dedicated spectrum is at least as good as operating in TVWS opportunities in all locations. In 66% of the locations the business case is strictly better for licensed spectrum. In the other 33% of the locations it is found that the utility for both cases, using TVWS and an equivalent amount of licensed spectrum, turns out to be zero. The reason for this is that the realizable TVWS capacity with the chosen channel selection criterion is zero, i.e., in these areas no TV channel supports the coverage requirements set by the cellular network. When this is the case we simply assume that the operator does not deploy any equipment in the area and hence no revenue or cost is associated with it.

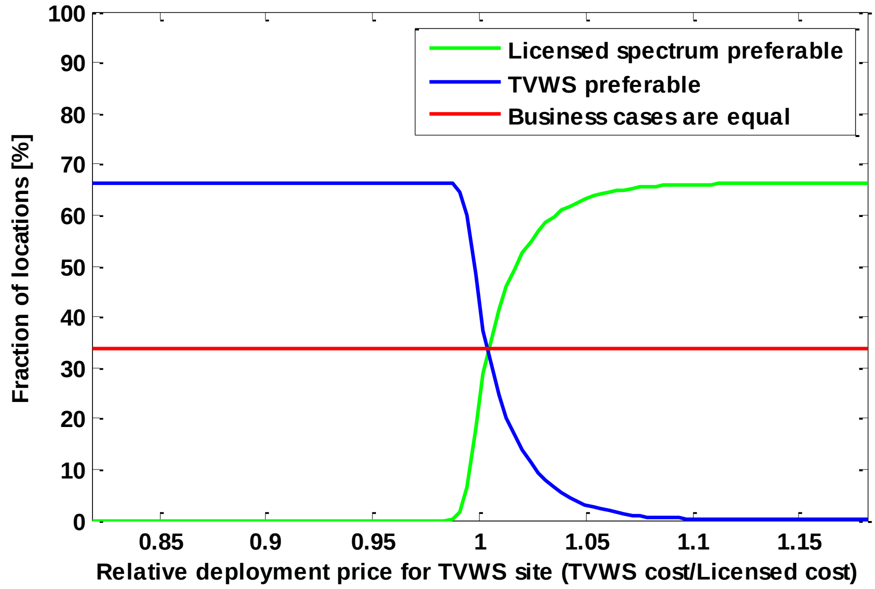



Figure 5-4: Relative TVWS site deployment cost vs. fraction of locations with better business case for the two options: a stand alone macro-cellular network operating in TVWS or in licensed spectrum. The figure is for the same case as in Figure 5-3.

It should be noted that the results are dependent on the difference in deployment cost for the two cases. Considering the same scenario as above and varying the deployment cost for the TVWS sites we obtain Figure 5-4 above. For only a slight extra cost above the deployment cost for a site in licensed spectrum, i.e., above 110k€ and relative cost 1, gives a large increase in the fraction locations where the business case for licensed spectrum is strictly better. The curve converges quickly to 66% of the locations and as argued above for the remaining 33% of the locations the utility of the two cases is zero due to zero TVWS capacity (illustrated by the red line in the figure).

If the deployment cost of a TVWS site is more than 2 k€ larger than the deployment cost for a site using licensed spectrum the business case for using licensed spectrum is better in most locations. Hence for the assumed TVWS site deployment cost of 160k€ (relative cost 1.45) using licensed spectrum is preferable. This conclusion remains true even under large variations (up to about 45k€) of the assumption.

Which business case is preferable also depends on the spectral efficiency of the system using the licensed spectrum. The fraction of German locations in which using licensed spectrum is preferable is shown for a set of assumed spectral efficiencies in Figure 5-5 below.

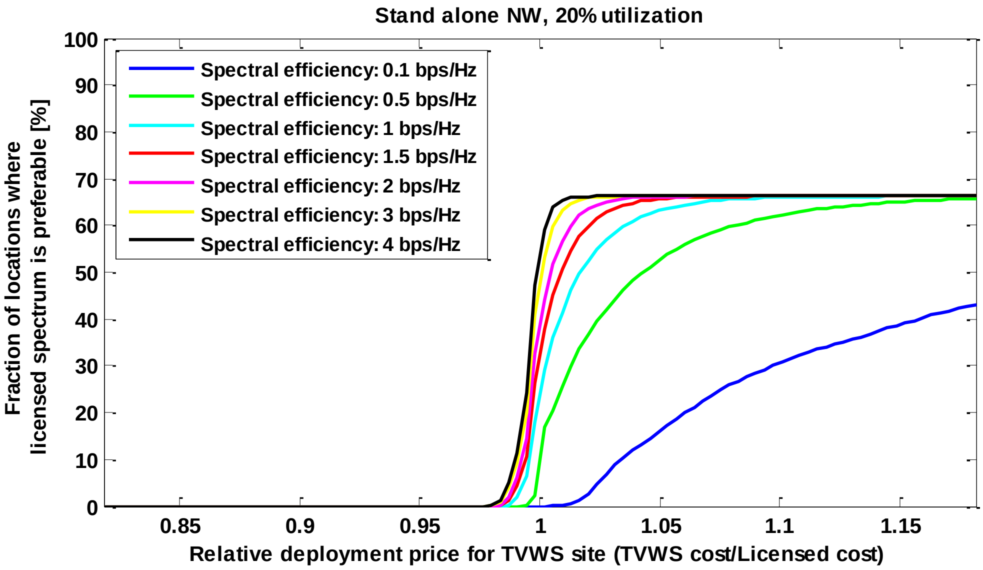



Figure 5-5: Fraction of locations in which using licensed spectrum provides a better business case than using TVWS, for various spectral efficiencies. The figure is for the same case as in Figure 5-3.

As expected the business case for licensed spectrum becomes better with increasing spectral efficiency in licensed spectrum. It is however important to note that for equal deployment costs and a spectral efficiency of 3bps/Hz in licensed spectrum the business case for using licensed spectrum is better for almost all locations. The reason for this is that when the spectral efficiency is increasing the cost for licensing an equivalent BW of dedicated spectrum becomes negligible compared to the TVWS database access cost, which is here kept constant. Again we find that the conclusions that using licensed spectrum is preferred in almost all locations even if we vary the assumption on the relative deployment cost quite much and the spectral efficiency is above 0.5bps/Hz.

Next, we investigate the impact on the conclusion by varying the license cost of dedicated spectrum. The result is shown in Figure 5-6 below.

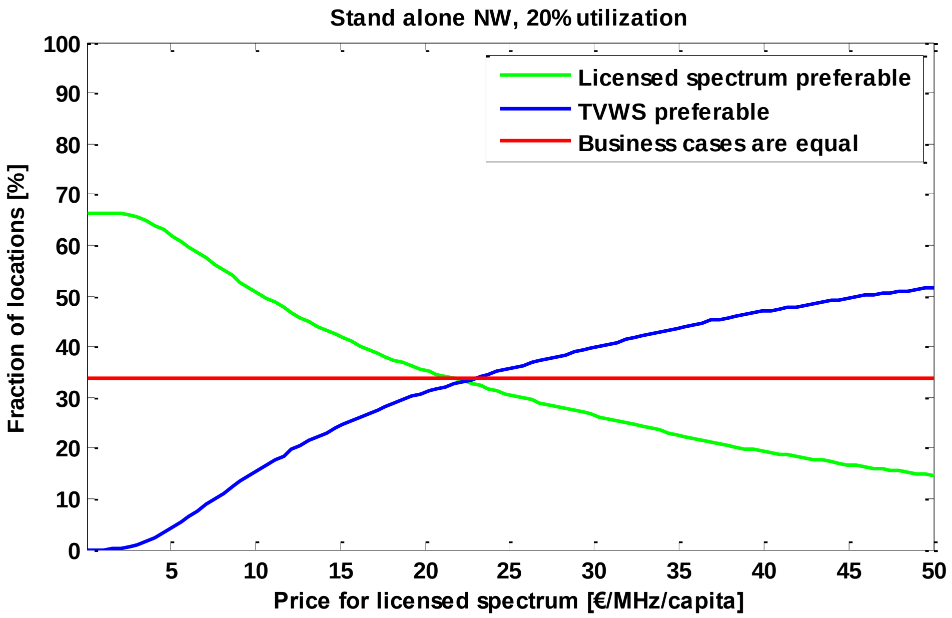



Figure 5-6: Impact of varying the price of licensed spectrum. The figure is for the same case as in **Error! Reference source not found.**.

If price for spectrum is less than 20€/MHz/capita, i.e., very expensive, using licensed spectrum is preferable. Hence, the assumed value of 0.75€/MHz/capita is far below that price and the conclusion will hold under large variations of the spectrum price.

### 5.2.3 DSA enabled macro cellular LTE network

Having compared the business cases of a stand-alone macro LTE network operating in TVWS to the case of using dedicated spectrum for the same network in the previous section we turn to the second case: An operator extending the capacity of an already existing network by exploiting TVWS opportunities, i.e., the DSA enabled network. In this case we consider only the utility of the TVWS capacity extension part of the network. No cost is associated with the legacy part of it, i.e., the part ensuring coverage. In the locations where a channel selection criteria provides additional capacity a number, depending on the population density in the area, of sites are upgraded with capability to provide extra capacity. This upgrade is associated with the total site upgrade cost part of the CAPEX. It should be mentioned that no new sites are assumed to be deployed to provide the capacity extension. Also the operator is assumed to be required to pay a TVWS database access fee for each subscriber.

In the other business case, where the operator invests in an equivalent bandwidth in dedicated spectrum producing the same capacity as is obtained by a DSA enabled network using TVWS opportunities, the operator invests in licensed dedicated spectrum and site upgrades but does not need to pay the TVWS database access cost.

Comparing the business cases for the two options of accessing spectrum we find that in about 95% of German locations it is preferable to use licensed spectrum, see Figure 5-7 below.

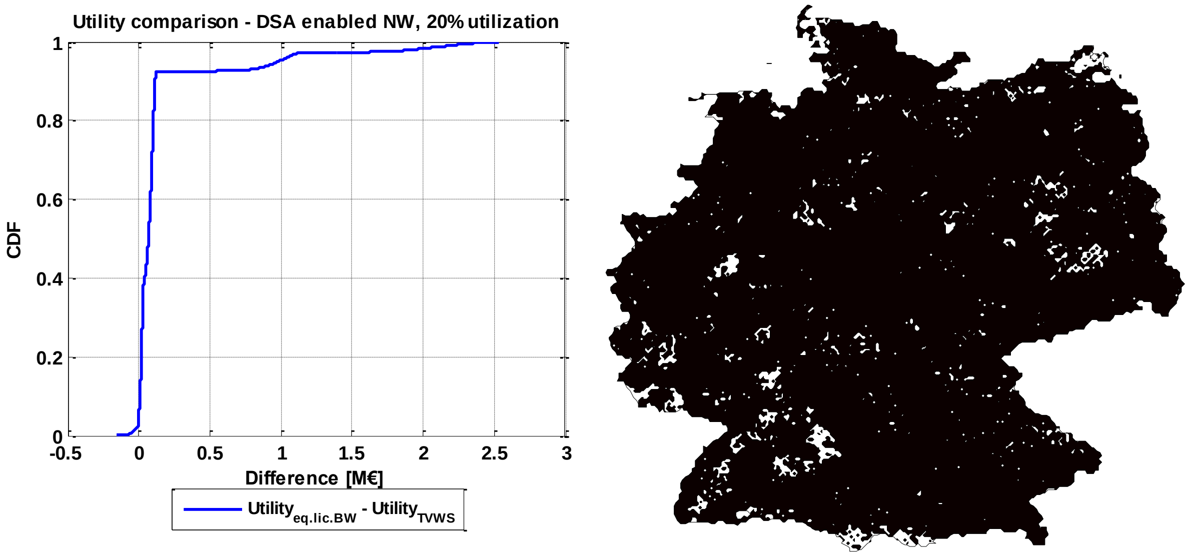



Figure 5-7: Comparison between the utilities of a network using equivalent amount of spectrum and a network using TVWS opportunities.

Thus, just as for the case of the stand alone network, in the DSA enabled case we find that in this scenario it is preferable for an operator to use licensed dedicated spectrum over TVWS.

As we did for the stand alone network scenario we now investigate the effect of varying the parameters in the model to see how sensitive the conclusions are to such variations. The result from varying the TVWS equipment costs (site upgrade cost) is shown in Figure 5-8.

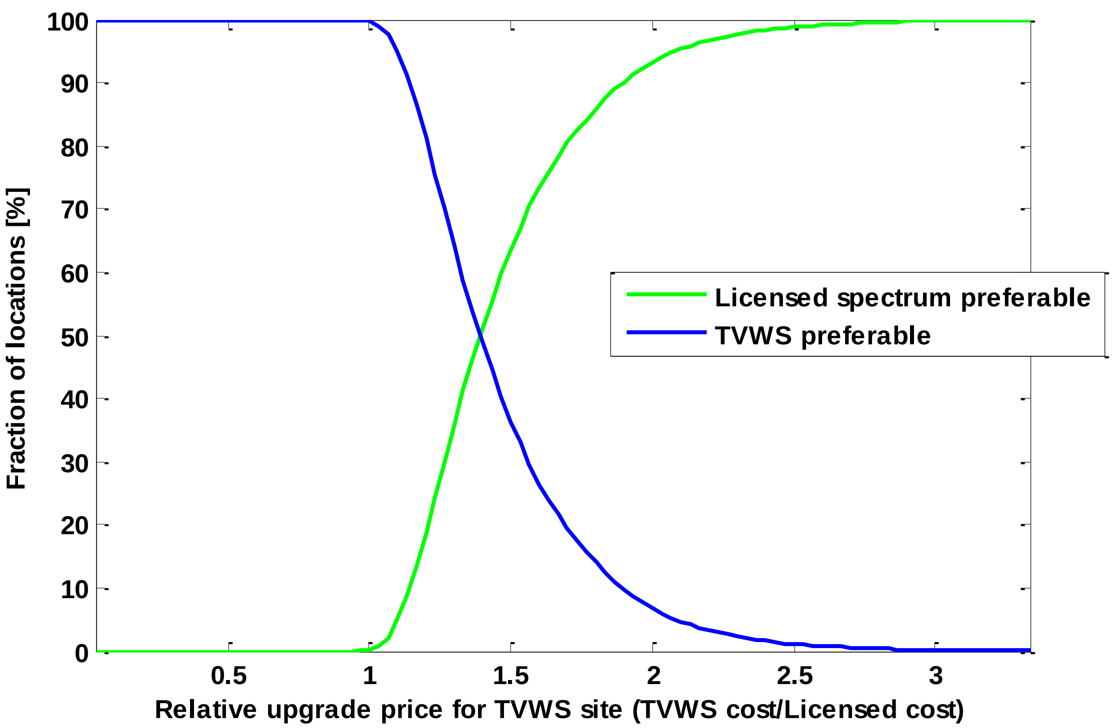



Figure 5-8: Dependence of the fraction of locations that has a certain preferred business case on the relative TVWS site upgrade cost.

From this figure it is clear that the increasing the cost for upgrading a site with TVWS capability affects which business case is the most beneficial for a DSA enabled network. Break even for this case, i.e. at 50% of the locations have a better utility for each option, is reached when the TVWS site upgrade cost is increased by a bit more than 10k€, i.e. 33% of the assumed cost for upgrading a site to support a larger licensed bandwidth. For larger TVWS upgrade costs the business case for using licensed spectrum becomes preferable in most locations. For lower upgrade costs the TVWS business case becomes preferable in most locations. The assumed value of the TVWS upgrade cost of 60k€ corresponds to a relative upgrade cost of 2, showing that minor variations of this assumption does not change the conclusion that using licensed spectrum is preferable in most German locations.

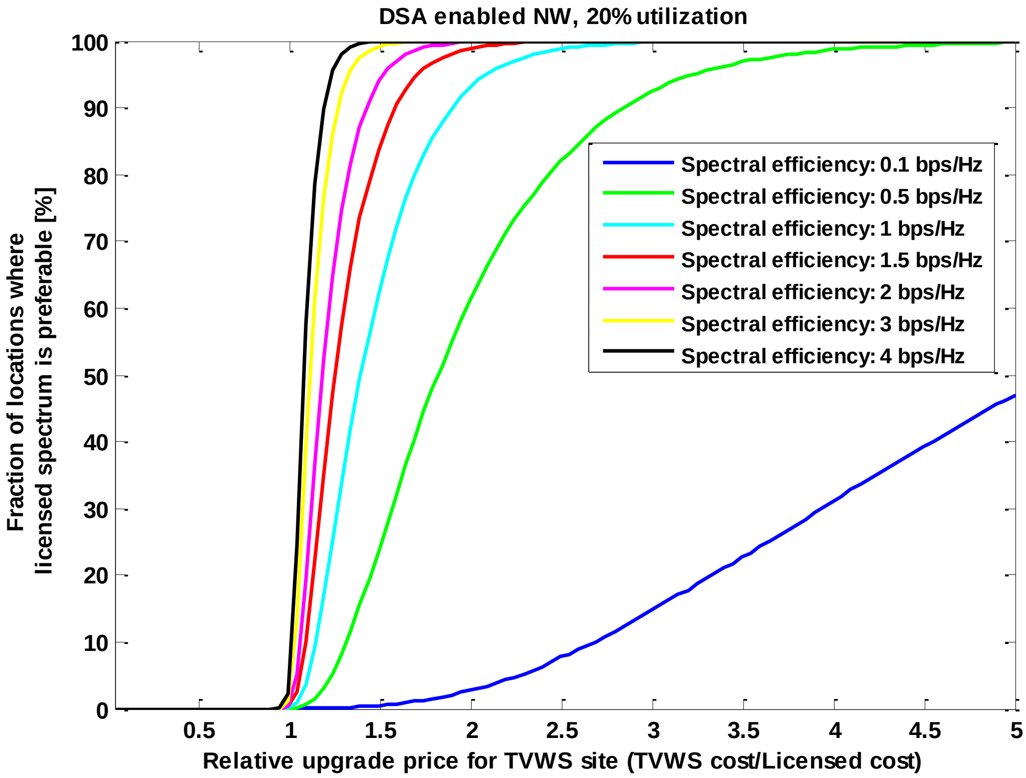



Figure 5-9: Impact of varying the relative site upgrade cost and the spectral efficiency in licensed spectrum.

From Figure 5-9 we find that as expected the business case for using licensed spectrum becomes better with increasing spectral efficiency in licensed spectrum. This is due to the bandwidth that needs to be licensed is reduced with increasing spectral efficiency and hence the price for licensing that bandwidth goes down. Considering the assumption of a relative upgrade price of 2 we find that as long as the spectral efficiency is above about 0.5 bps/Hz licensed spectrum usage is preferable in most locations. Hence, as long as the operator uses a reasonably spectral efficient cellular system the using licensed spectrum provides a better business case than using TVWS opportunities.

For lower relative site upgrade costs, increasing the spectral efficiency of the cellular systems increases the fraction of German locations where licensed spectrum is preferred. Since the development of cellular systems constantly strives to improve the spectral efficiency the business case for using licensed spectrum will only become more and more preferable over time, hence reducing the competitiveness of using TVWS opportunities for cellular system capacity enhancements.

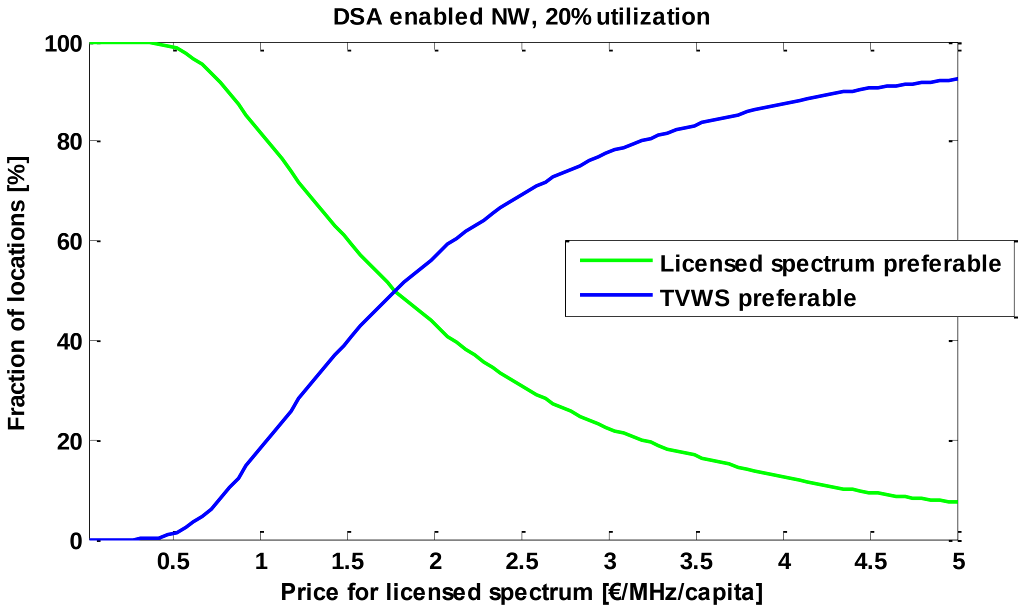



Figure 5-10: Impact of varying the price of licensed spectrum.

Figure 5-10 illustrates the dependence of the spectrum price on the fraction of locations in which a particular business case is preferred. Recall that we have assumed above a price of 0.73 €/MHz/capita which clearly results in that using licensed spectrum in most of the locations is preferable. The conclusion holds as long as the price for licensed spectrum is less than ~1.70€/MHz/capita, which is more than twice as much as the assumed value. Hence, the conclusion is robust to minor variation in the spectrum price.

### 5.2.4 Comparing a traditional licensing scheme to using TVWS for a DSA enabled macro cellular LTE network

We acknowledge that the assumption of licensing spectrum on smaller areas than entire countries is not a possibility in present regulations. For this reason we now briefly discuss the implications on the conclusion on the preferable business case for a DSA enabled network if we consider the present day possibilities.

To this end we assume that a cellular operator needs to license spectrum in the entire country. Further, we require that the capacity of the communication using licensed spectrum should be at least as good in all areas as what is realizable in the same area as when using TVWS opportunities. This means that we require the operator to license the amount of spectrum corresponding to the maximum value of the equivalent licensed bandwidth needed in Germany.

To remove the dependence on the revenue and OPEX in the comparison we assume that the operator doesn't allow a subscriber to use more data traffic than he/she would have been able to if TVWS opportunities were used. This clearly is suboptimal use of the licensed spectrum, and it should be noted that this limits the possible incomes for the operator. For this reason the studied case should be seen as a lower bound of the total utility that corresponds to licensing the spectrum in this way.

For all numerical evaluations, presented below in this section, we use the TVWS channel selection criteria of requiring that the median user bit-rate spectral efficiency is larger or equal to 25% of the median user bit-rate in dedicated spectrum. We further use TVWS capacity data corresponding to 20% utilization of the macro cellular network.

We now investigate the difference in total utility between using this amount of licensed spectrum and using TVWS opportunities for some values of relative site upgrade cost (i.e., the ratio between the TVWS site upgrade cost to the cost of upgrading a site to support additional licensed spectrum). The difference in the total utility, i.e., when summing the utility over all considered areas in Germany, is shown in Figure 5-11.

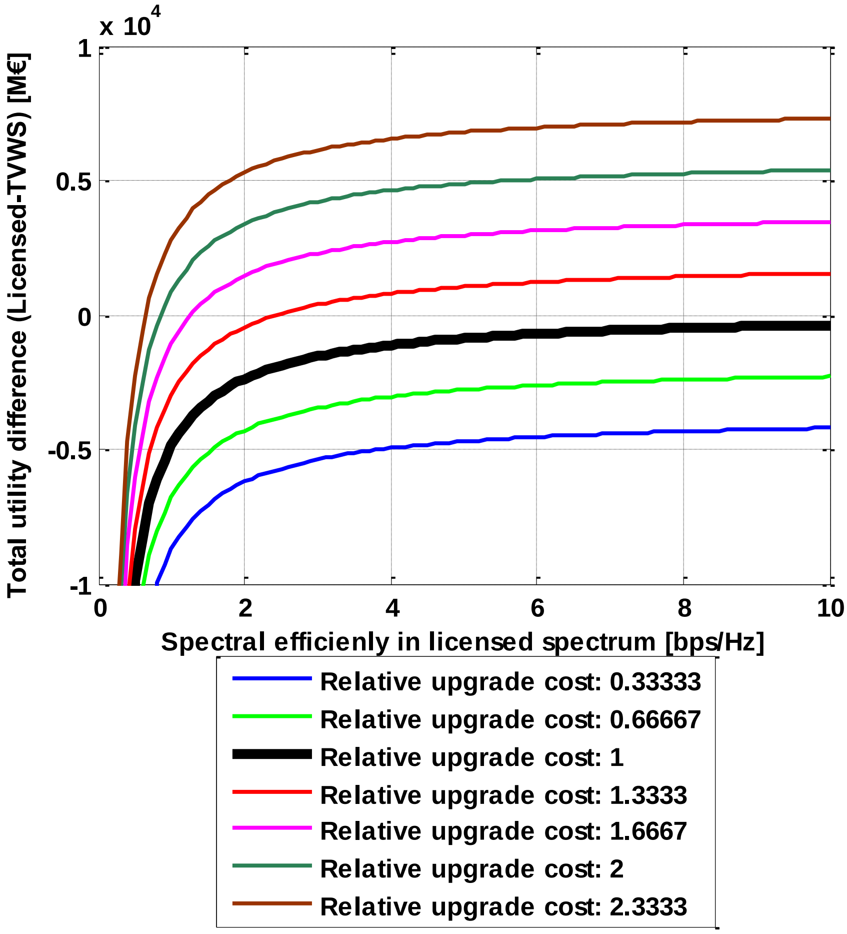



Figure 5-11: Difference in total utility between the case when using licensed spectrum and the case when using TVWS opportunities, for the case when spectrum is only licensed on country basis.

From the figure above the dependence on the relative site upgrade cost is apparent. If the relative site upgrade cost is lower or equal to 1, i.e., upgrading a site to handle TVWS opportunities is cheaper than, or equal in cost to upgrading a site to use more licensed spectrum the business case for using TVWS is found to be preferable for the considered range of spectral efficiencies. However, a relative site upgrade cost below or equal to 1 will hardly be realizable in the near future since the market for using TVWS is immature. As the relative site upgrade cost is increased beyond 1, the required spectral efficiency for making the business case of using licensed spectrum preferable decreases, see Table 5-3 below.

Table 5-3: Relation between relative TVWS site upgrade cost and the spectral efficiency that give the total utility for using TVWS and licensed spectrum equal.

| **Relative TVWS site upgrade cost** | **Spectral efficiency for equal business cases (above which using license spectrum becomes preferable).** |
|---|---|
| 1.33 (40k€) | 2.45 bps/Hz |
| 1.66 (50k€) | 1.30 bps/Hz |
| 2 (60k€) | 0.85 bps/Hz |
| 2.33 (70k€) | 0.65 bps/Hz |

From this we learn that for a relative TVWS site upgrade cost of 2 (the operating point assumed in the previous sections) a spectral efficiency of about 0.85bps/Hz give equal total utility for the two cases, using TVWS or licensed spectrum. For an LTE system such spectral efficiency it to be considered as low and values in the order of 2bps/Hz will be observed in real life LTE deployments [TR36912]. Hence the business case for using licensed spectrum is better than the business case when using TVWS opportunities.

Remember that the business case for using licensed spectrum will in reality be even more positive since we above have assumed that not all licensed bandwidth is used but constrained to give the same capacity as when using TVWS opportunities.

We conclude that the business case for using licensed spectrum is preferable even if the operator is required to invest in licensed spectrum in the entire country.

## 5.3 Discussion and conclusions

By using the utility model presented above, both for a stand alone and for a DSA enabled macro cellular LTE network, we find indications that it is more beneficial in most cases to invest in an equivalent bandwidth of licensed dedicated spectrum over using TVWS opportunities.

This may be derived to the relative cheapness of buying spectrum, but also to the price difference assumed between deploying equipment for licensed dedicated bands and TVWS opportunities. The latter price difference may become smaller as TVWS equipment becomes more common and market volumes become larger. However, by the time volumes have gone up the spectrum situation may have changed and the above results would not be applicable. As such the capacity data used in this study is accurate in the present TVWS situation in Germany, i.e., no second digital dividend has taken place.

It should be stressed that the assumption on the possibility to buy spectrum licenses per area has been made to be able to compare the business cases on a basis that eliminate the revenue and OPEX from consideration in that the provided capacity becomes the same. At present such licensing is not possible and the licenses are issued on a per country basis. It would be more expensive for an operator if it needed to license the spectrum for the entire country, making the business case less favourable. The assumption has been made to make the two options comparable and removing it makes the comparisons even more sensitive to parameter assumptions.

In summary: We have shown that in Germany, and under reasonable assumptions, a spectrum licensing scheme for smaller area units in combination with a second digital dividend would provide a better business case for cellular operators than investing in TVWS equipment. We have also shown that this conclusion holds even if the parameters representing the assumptions are varied moderately. Furthermore, the conclusion holds also when a more traditional licensing scheme is used and realistic spectral efficiencies for an LTE system operating in dedicated spectrum is assumed. This then motivates the need for a second digital dividend that would open up the possibility to dedicate an additional part of the TV bands to be used by other systems. From a cellular system perspective such a dividend would be more beneficial than if the TV band would be opened up for secondary use.

# 6 Business Analysis of Cognitive Machine-to-Machine scenario

## 6.1 Introduction

Practical applicability of cognitive radio (CR) attracts keen attention by the wireless industry and academia. A key underlying assumption within CR is that the radio frequency spectrum is in shortage as compared to the increasing demand for wireless data services. TVWS has taken center stage as an operating spectrum for CR. On the other hand, there has been less interest in secondary use of the cellular band by regulatory bodies, with the reason that it is heavily used and already sustains the type of traffic for which demand is exploding. However, cellular bands have some merits in the business perspective. The operators can obtain the exclusive rights to use the cellular bands through auction or beauty contests. It makes clear ownership of cellular bands. Moreover, cellular bands already have mature ecosystem for business. Thus, we need to investigate the business opportunity of CR services which use cellular spectrum. In this chapter, we focus especially on cognitive M2M (infrastructured) in cellular spectrum, which is the one of CR service scenarios described in section 2.1. Let us define M2M service provider (MSP) as a company who wants to provide M2M service. A power company can be an example of MSP when it intends smart grid/metering service. If a MSP does not have its infrastructure for the M2M service, it should make a contract with a mobile network operator (MNO) who owns the right to use cellular spectrum. Through this contract, the MSP can initiate its M2M service with the cellular bands, and there are two options according to the structure of M2M communication: MVNO-MSP and cognitive radio-MSP (CR-MSP).

- In MVNO-MSP, M2M devices directly access the radio access network of cellular system, and can be individually managed by a MNO based on 3GPP machine type communication (MTC) standards.
- In CR-MSP, M2M data is at first gathered by cluster headers in hierarchical structure. When M2M devices transmit their packets to a cluster header, CR technique is used, and the cluster header forwards the collected data to the radio access network of cellular system with the similar access process to primary users (e.g., cellular users).

To verify the business opportunity of cognitive M2M in cellular bands, we compare the above two types of M2M services. MVNO-MSP can guarantee better performance of M2M services with exclusive rights to use the cellular bands and with elaborate management from the MNO. However, excessive number of M2M devices can cause a significant congestion/overload problem in the control plane of cellular network. It is estimated that the number of devices that require wireless connectivity will reach 50 billion in 5-10 years [Ericsson11]. To cover massive number of M2M devices in MVNO-MSP, MNO needs to upgrade its infrastructure and bandwidth, and eventually it leads to higher fee to MSP. On the other hand, in CR-MSP, cognitive transmission between M2M devices and cluster headers reduces the number of access to the cellular network. Therefore, CR-MSP may solve the congestion/overload problem in M2M services, even though it is hard to provide as high quality of M2M service as in MVNO-MSP.

In the following chapters, we find the condition that CR-MSP is preferable to MVNO-MSP in business perspective in section 6.2, and investigate the feasibility of our cognitive M2M comparing with 3GPP MTC in section 6.3 based on smart metering service. In section 6.4, we briefly check on using TVWS for M2M communications and make a conclusion.

## 6.2 Secondary spectrum access and cognitive M2M communication

### 6.2.1 Cognitive M2M communication

In M2M communications, the machine includes all levels of devices with communication functionality embedded. M2M communication is defined as a sort of data communication between machines that do not necessarily need human interaction [TR22868]. It is expected that a number of machines could communicate each other easily by M2M communications, mostly with wireless connections. In industry, it is estimated that the number of machines that require wireless connectivity, either among themselves or to the Internet for their operation, will reach about 50 billion in 5-10 years [Ericsson11]. Prominent examples of this M2M communication include smart grids/smart metering, car-to-car and car-to-infrastructure communications, monitoring of industrial plants and agriculture, and cloud computing, etc. The data requirements for such applications may initially be low and limited. As M2M technologies advance, however, higher volume of data communication is expected in a case like home networking where all appliances are connected to and interact with each other.

M2M communications are currently under investigation by ETSI[14], 3GPP, 3GPP2 and IEEE 802.16m. Machine type communication (MTC) is the name of M2M communication in 3GPP, and 3GPP consider that M2M devices operate similarly to the user equipments for human-to-human (H2H) communications to communicate with M2M servers. Thus, ad hoc networking among machines is the beyond scope of the cellular industry oriented bodies like 3GPP, 3GPP2 and IEEE 802.16m [LCL11]. On the other hand, sensor/RFID network community considers M2M as an extension of the current sensor/RFID networks, where most of the communications are of ad hoc type, and free from the control of any operators. Thus, there are a lot of different M2M use cases by different working bodies, which may bring competition among some of them in the future due to overlaps.

Cognitive radio, on the other hand, is emerging as a technology for M2M communication. While TVWS is thought to be the target bands of M2M communication in most researches [Zhang12, GBL10, WGC11], the cellular band as a primary spectrum gains much attention because it is the main spectrum for commercial wireless communications [GPE09; WMBW09; FMD11]. However, noting that there has been much engineering debate on CR, there is still a clear lack of business-oriented CR research. In particular, even less has been written about the real business value of the secondary use of the cellular band. The purpose of this section is to analyze the business value of the secondary use of the cellular spectrum, especially in cognitive M2M communication scenario.

Figure 6- 1 shows the concept of our cognitive M2M communication with the conventional cellular systems (infrastructured). Cognitive M2M has a hierarchical structure with cluster headers, which can directly communicate with the base station as primary cellular users. The cluster headers gather M2M traffic from M2M devices and forward it to the base station of cellular network. In this gathering process, multiple M2M devices as secondary users send their data to the cluster headers using CR technique, without requiring additional radio resources. In this cognitive M2M communication, we consider smart metering type of M2M services. The usage time for smart metering service is very short or limited, and the traffic volume of each device is small. QoS requirements for the secondary services are low because neither low latency nor high throughput is required for the metering type of communication. In some M2M use cases, M2M devices can require high QoS or have high traffic volume. These traffic conditions are not suitable for CR, and those M2M use cases are out of scope in CR business.

For cognitive M2M communications, a geo-location database containing information on the primary user may not be available to the secondary, due to the mobility of the

[14] ETSI, http://www.etsi.org/Website/Technologies/M2M.aspx.

primary users, i.e., cellular users. Instead, interweave or underlay approach can be considered here for cognitive transmission between M2M devices and their cluster headers. In both cases, spectrum sensing and/or power control is needed to protect the cellular users. To reduce the complexity and the cost of M2M devices, it is efficient that the cluster headers take charge of spectrum sensing and power control in our hierarchical operation.

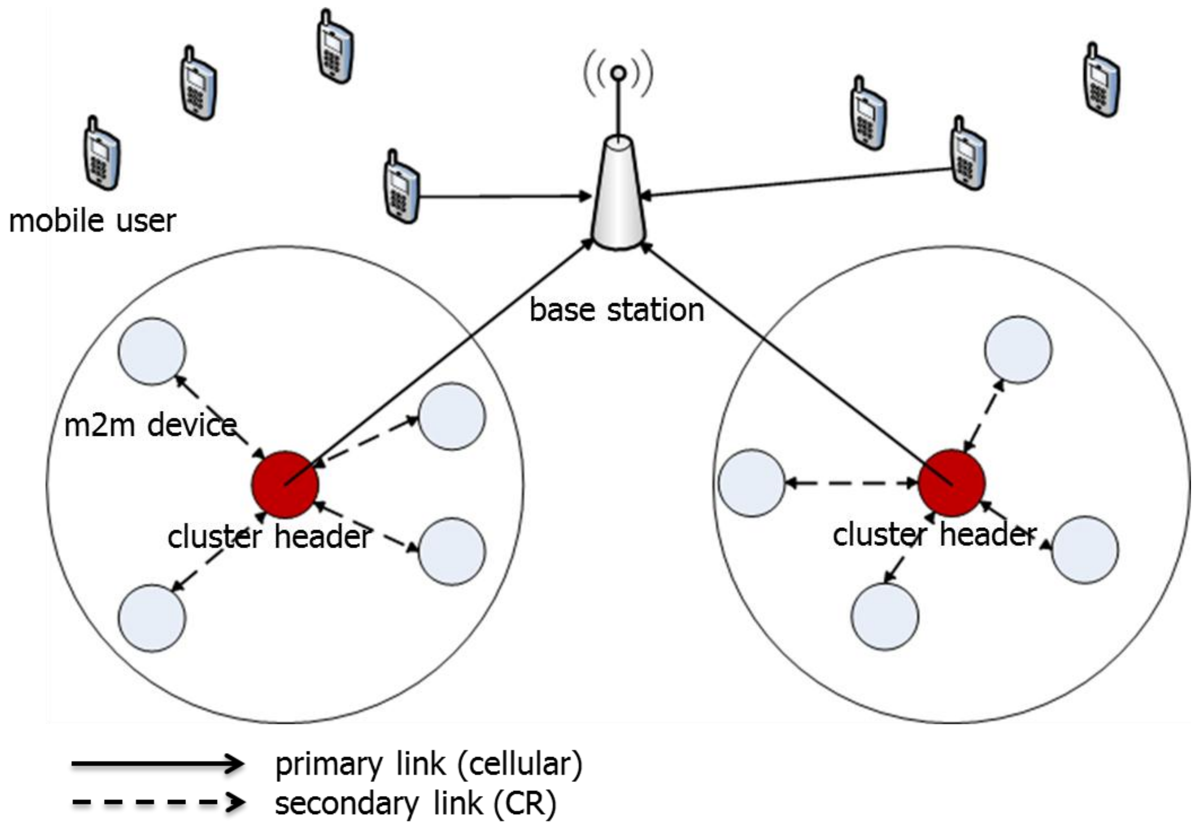



Figure 6- 1: Hierarchical operation in cognitive M2M

### 6.2.2 Cognitive M2M versus 3GPP MTC

In 3GPP MTC standards, each M2M device directly accesses the cellular network. This can provide higher performance of M2M service, being scheduled and managed by the cellular operator. However, it is hard for cellular operators to control overmany M2M devices with limited resources of cellular network. For this congestion issue on radio access control channel (RACH), 3GPP propose some solutions such as access class barring, separate RACH, and pull-based schemes [TR23888]. The cognitive M2M can be an alternative solution for the congestion/overload problem of M2M communication, which is happened when excessive number of M2M devices tries to access the cellular network with MTC standards.

In Table 6- 1, we compare our cognitive M2M with 3GPP MTC. Both cognitive M2M and 3GPP MTC use the cellular bands for outdoor M2M communication. The differences between two systems are spectrum sharing type and license type. In 3GPP MTC, each M2M device is scheduled in an exclusive radio resource and controlled by the cellular operators, as a primary cellular user. In cognitive M2M, however, multiple M2M devices may use the same radio resource simultaneously using interweave or underlay CR technique.

Table 6- 1: Comparison of Cognitive M2M and 3GPP MTC

| | *Cognitive M2M* | *3GPP MTC* |
|---|---|---|
| *Secondary usage type* | Outdoor | Outdoor |
| *Spectrum sharing type* | Interweave or underlay | Scheduling |
| *License type* | Secondary sharing license | Exclusive license |
| *Primary system* | Cellular bands | Cellular bands |
| *Transmission and duplex Mode* | DL+UL (FDD or TDD) | DL+UL (FDD or TDD) |

To analyze the feasibility of cognitive M2M services in economic aspects, we should consider the cost needed for M2M services and the benefit which can be achieved from M2M services. The notations are listed as follows.

- $N_u$ : number of M2M service users
- $N_h$ : number of CR-M2M header nodes
- $R_i$ : revenue of service provider *i* from M2M services
- $P_n$ : cellular infrastructure network usage fee (per device)
- $P_m$ : M2M service usage fee (per device)
- $C_a$ : network administration cost (per device)
- $C_m$ : M2M device producing cost (per device)
- $C_h$ : CR-M2M header device producing cost (per device)

$C_h$ is larger than $C_m$ because implementation cost of CR technology is included in $C_h$.

With those components, we can construct the cost structure of any M2M service scenario. However, it is hard to figure out the actual values of each scenario, because M2M service is still in development. Thus, we will compare the relative costs of the following two scenarios with different operators, where M2M service uses the LTE cellular bands:

1. Mobile Network Operator (MNO) + MVNO-M2M Service Provider (MVNO-MSP): MV NO-MSP operates M2M service, leasing the infrastructure and spectrum from NSP.
2. MNO + CR-MSP: CR-MSP takes part in M2M services with cognitive technology. Si milar to MVNO-MSP, the CR-MSP borrows the infrastructure and spectrum from MNO. The difference between MVNO-MSP and CR-MSP is in their spectrum license types. In this scenario, MNO gives spectrum license for multiple CR-MSPs with lo w price, because the license is shared between them. Thus CR-MSP can minimize the spectrum cost.

In scenario 1, the revenue (net profit) of MNO $R_{MNO}$ is

$$R_{MNO} = N_u \cdot P_n - N_u \cdot C_a \, .$$

There are $N_u$ paid subscribers. The MNO should support these users. We assume that the network administration cost increases with the number of subscribers. If net profit of MNO is less than zero, there is no reason to stay in business. Therefore, the business feasibility condition for MNO is $R_{MNO}>0$. Thus,

$$N_u \cdot P_n - N_u \cdot C_a > 0$$

$$P_n > C_a \, .$$

To decide the network usage fee $P_n$, the MNO only interests in network administration cost $C_a$. For this reason, we assume that $P_n$ is the same in both scenarios.

The revenue of MVNO-MSP $R_{MNO}$ is

$$R_{MVNO} = N_u \cdot P_m - N_u \cdot C_m - N_u \cdot P_n .$$

The business feasibility condition for MVNO-MSP is $R_{MVNO}>0$. Thus,

$$N_u \cdot P_m - N_u \cdot C_m - N_u \cdot P_n > 0$$

$$P_m > C_m + P_n .$$

MVNO-MSP should consider device producing cost and network usage fee on pricing.

In scenario 2, the revenue of MNO $R_{MNO}$ is

$$R_{MNO} = N_h \cdot P_n - N_h \cdot C_a .$$

In our hierarchical model (Figure 6.2), only cluster header nodes are associated with cellular network. Thus, the header nodes are charged, not M2M user devices. The business feasibility condition for MNO is the same as scenario 1.

$$P_n > C_a .$$

The revenue of CR-MSP $R_{CR}$ is

$$R_{CR} = N_u \cdot P_m - (N_h \cdot C_h + N_u \cdot C_m) - N_h \cdot P_n .$$

$N_u P_m$ is total profit from M2M service. $N_h C_h + N_u C_m$ is total manufacturing cost, and $N_h P_n$ is network usage cost.

The business feasibility condition for CR-MSP is $R_{CR}>0$. Thus,

$$N_u \cdot P_m - N_h \cdot C_h - N_u \cdot C_m - N_h \cdot P_n > 0$$

$$P_m > \frac{N_h}{N_u} \cdot C_h + C_m + \frac{N_h}{N_u} P_n .$$

We denote a ratio of the number of header nodes to the number of M2M users as $\Theta=N_h/N_u$, $0<\Theta\leq 1$. If $\Theta$ is small, the level of development of CR technologies is high. If $\Theta$ approaches 1, the level of development of CR technologies is low.

Let us compare $P_m$ in both scenarios. If service fee of CR-MSP is cheaper than MVNO-MSP, the M2M service user may choose CR-MSP. Thus, the service feasibility condition for CR-MSP is

$$C_m + P_n - (\theta \cdot C_h + C_m + \theta \cdot P_n) > 0$$

$$\theta < \frac{P_n}{C_h + P_n}.$$

The above condition means if CR technology is well developed ($\Theta \fallingdotseq 0$), the CR-MSP can provide always lower service fee than MVNO-MSP. If the level of CR technology is low ($\Theta \fallingdotseq 1$), the network usage fee $P_n$ should quite high to satisfying the service feasibility condition. And the header node producing cost $C_h$ should be low. Thus the development of CR technology and network usage fee would be the key parameter for the pricing policy of M2M services.

## 6.3 An example of cognitive M2M services: Smart metering

One of the most prominent examples of cognitive M2M communication is smart metering. A large number of metering machines would attempt to use spectrum simultaneously to monitor the energy consumption and improve the energy usage. Metering machines are deployed 4968/cell to 35670/cell corresponding to central London and urban London, respectively [TR37868]. Smart meters are the next generation of utility meters that provide accurate real time information on consumption to the users as well as the utility company [NXW11; FFKTIN11; LCL11]. It is expected that smart metering will play an important role in transforming most developed countries to a low-carbon economies [DECC09], and actually there are large scale attempts at deploying smart meters in many parts of the world, such as in Germany, Italy, USA (California), Canada, Australia, and New Zealand.

### 6.3.1 Engineering value of cognitive M2M

Smart metering service needs a large number of devices, which communicate using limited wireless resources. It may cause a significant congestion or overload problem to the network. Radio network congestion occurs when too many smart metering devices attempt to transmit data to the same eNodeB (Evolved Node B) simultaneously. In LTE networks, mobile terminals use random access procedure to attach the core network and synchronize uplink transmission with eNodeB. Every terminal randomly chooses a preamble code and sends the preamble message to eNodeB through RACH (Random Access Channel). The eNodeB then allows some terminals which use unique preamble code to access the network. However, collision occurs when more than two terminals send the same preamble code simultaneously.

A large number of smart metering terminals will bring higher collision probability and higher congestion in LTE networks of 3GPP MTC. In 3GPP specification meeting [R2], many companies discussed this RACH congestion issue and analyzed it with the parameters as shown in Table 6-2.

Table 6-2: Simulation Parameters for LTE FDD

| *Parameter* | *Setting* |
|---|---|
| *Number of MTC devices* | 5000, 10000, 30000 |
| *MTC devices arrival distribution* | Uniform distribution over 60s, Beta distribution over 10s |
| *Cell bandwidth* | 5 MHz |
| *Total number of preambles* | 54 |
| *Maximum number of preamble transmission* | 10 |
| *Preamble detection probability (in case of no collision)* | $1-1/e^{i}$ where *i* indicates the *i*-th preamble transmission |
| *ra-ResponseWindowSize* | 5 subframes |
| *mac-ContentionResolutionTimer* | 48 subframes |
| *Backoff Indicator* | 20ms |
| *HARQ retransmission probability for Msg3 and Msg4 (non-adaptive HARQ)* | 10% |
| *Maximum number of HARQ TX for Msg3 and Msg4 (non-adaptive HARQ)* | 5 |

Based on the same parameters, we evaluated the performance of LTE networks through OPNET simulator. In the simulation, 5000, 10000, and 30000 M2M devices try to access the single eNodeB through 54 preamble codes over 10 seconds with beta distribution. When preamble collision happens, every collided device selects the back-off timer between zero and back-off indicator uniformly. After back-off timer, each device retransmits the preamble packet to eNodeB. If the preamble packet does not succeed within the maximum number of preamble transmission, the M2M device fails the random access procedure. The wireless channel characteristic is simply considered with the preamble detection probability. Even if the preamble packet avoids the collision, the packet can be successfully received at eNodeB with preamble detection probability. Through OPNET simulator, four output values are measured; i) Collision probability, defined as the ratio between the number of preamble collisions and the overall number of RACH opportunities. ii) Access success probability, defined as the probability to successfully access devices. iii) Number of preamble transmissions, defined as the average number of preamble transmission until the completion of the random access procedure. iv)Access delay, defined as the average spends time for the random access procedure. The numerical example is shown in Table 6-3. As a result of this simulation, significant RACH congestion occurs in 30000 devices case. By using cognitive M2M, this performance degradation can be mitigated.

Table 6-3: Performance of 3GPP M2M

| *Number of MTC devices* | 5000 | 10000 | 30000 |
|---|---|---|---|
| *Collision Probability* | 0.643% | 5.074% | 74.185% |
| *Access Success Probability* | 100% | 97.6% | 48.6% |
| *Number of Preamble Transmission* | 2.014% | 2.983% | 5.0984% |
| *Access Delay (ms)* | 33.314 | 53.45 | 96.055 |

In cognitive M2M, hierarchical structure is adopted to solve this congestion situation. In interweave approach, the cluster header senses and finds the empty resource block (RB) of LTE network, and schedules a certain M2M device in the RB to gather M2M data from the devices. In underlay approach, the cluster header controls the transmission power of M2M devices and M2M devices send their data to cluster headers with the power, not degrading the primary cellular performance. After gathering some data, the cluster header accesses to eNodeB to forward the machine data with the similar access process to primary users. Thus, the number of attempts to access the eNodeB can be reduced, and congestion problem of M2M can be solved.

With the hierarchical structure, it also be able to use the various radio access techniques (RATs) and/or other spectrum bands for the secondary machine. Then, the machines can choose and adopt cheaper and more proper RAT and/or spectrum for their cognitive transmission, e.g., cognitive M2M with TVWS.

### 6.3.2 Business value of cognitive M2M

The cognitive M2M may be a good solution for providing M2M services, where the wireless traffic demand is bursty and rare in temporal domain. While acquiring an exclusive spectrum license or becoming a mobile virtual network operator (MVNO) would be expensive, the cognitive M2M can be a relatively low cost alternative. Comparing with MVNO, commercialization of the cognitive M2M is easier and the management cost is lower, due to the cognitive characteristics of the secondary transmission between M2M devices and cluster headers.

In smart metering scenario, the spectrum license ownership by the primary is high because the primary spectrum comes from cellular networks and the primary has the exclusive ownership of the spectrum license. When we assume that the primary operators are willing to sublicense their spectrum to secondary ones, the primary can contract with multiple secondary users. Therefore, the spectrum license ownership by the secondary is medium. The service differentiation between the primary and the secondary is medium as well. This is because the target service areas of both services are overlapping as urban areas, even if the cellular and smart metering services are quite different. Thus, the cognitive M2M in smart metering is promising in business perspective, especially with primary operators’ willingness to sublicense the spectrum to another operator.

In the ecosystem of the cognitive M2M for smart metering in LTE, there would be four types of players in total: mobile network operators, mobile users, smart metering service providers and smart metering users. All of them have some motivations to commercialize smart metering service based on the cognitive M2M communication. First, the mobile network operators, which are also mobile service providers in cellular networks in usual, can increase its total revenue and profit by making more contracts with the multiple smart metering service providers (not only as MVNO, but also as secondary license owners). As mobile service providers, they are expected as well to make money by creating new value-added services such as remote power control and monitoring service using cellular phone. Second, the mobile users can enjoy those new convenient services with their cellular phones. Third, the smart metering service providers can apply the cognitive M2M communication technologies to their business at relatively low cost. They will be able to manage their resource (power) easily by using the communication technologies. Finally, the smart metering users will use the smart metering service without paying much. Moreover, they will be able to save power cost by monitoring and managing their power consumption level in real time.

## 6.4 Conclusions and comparison with cognitive M2M in TV white spaces

CR technology is expected to play a significant role in filling the gap between the shortage of spectrum and growing demand for wireless applications. In particular, the use of the cellular band by the secondary CR operators in the cognitive M2M communication seems to have promising business opportunities, given that the secondary operators may lease spectrum under agreements with license holding operators.

This section suggests the use of the cellular band by the secondary CR operators focusing on the business value as well as engineering value of the cognitive M2M communication in the smart metering service. We believe that the cognitive M2M may be a good candidate for smart metering service whose traffic is bursty and very short, in spite of the hurdles that still need to be overcome. First of all, the specific and innovative business models for the cognitive M2M should be invented in order to vitalize the cognitive M2M ecosystem. In addition, the regulatory framework must be advanced to allow the secondary service providers to lease spectrum or share licenses.

On the other hand, TV bands are considered as a promising spectrum for secondary services in CR, due to the radio characteristics such as long signal ranges, excellent in-building penetration, and its worldwide harmonization [SSW09]. Moreover, TVWS are being regulated as free and unlicensed basis in the USA and the UK. These merits attract interests of M2M operators as well as the standardization for using TVWS in CR is now being processed in IEEE: 802.11af [IE80211] and 802.22 [IE80222]. In IEEE802.11af, there are efforts under way to modify both the 802.11 physical layer and the medium access control layer, to meet the requirements for channel access and coexistence in the TVWS. IEEE802.11af considers M2M services using TVWS with a geo-location database based cognitive radio. IEEE802.22 is the working group on Wireless Regional Area Networks (WRANs) and is to develop a standard for a cognitive radio-based PHY/MAC/air interface in TVWS. However, the IEEE 802.22 does not appear to include much support for M2M. A white space M2M standards body, Weightless [WEIGHT] is been launched based in Cambridge. In industry, prototype devices and TVWS solutions are in development by a few vendors such as Spectrum Bridge [SB] and Carlson Wireless [CW], and Neul [NEUL]. Neul in the UK announced that its wireless radio system, NeulNET, was successful in the first showcase and is under way in Cambridge for commercial trials.

Despite of all the above merits of TVWS, however, the TVWS ecosystem is immature. The regulation is still at an early stage and the geo-location databases for TVWS are only available in the US. Some network equipment, chipsets, and devices for TVWS applications are being emerged now, but the solutions for them are hardly available as ever. Especially, the lack of infrastructure for TVWS is a major obstacle to commercialize the infrastructure based M2M services in TVWS. Thus, it will take long time to build up the ecosystem to fulfill the demand of M2M services that rapidly increase.

Therefore, for the present, M2M services should utilize the existing infrastructure and the ecosystem which are already mature, such as cellular networks. The cellular network provides a solution for M2M services, named machine-type communication (MTC). However, the cellular networks (e.g., GSM, UMTS, LTE) are oriented to support the human-to-human (H2H) communication and it would bring some difficulties to handle too many machine devices, and 3GPP has been working on this congestion problem [TR23888]. Also with CR technique, the congestion in the radio access network and control signal overhead of MTC can be solved, as proposed in section 7.2. However, due to its sensing based CR approach and small size of resource block, the cognitive M2M may be inappropriate for the services with high traffic volume (e.g., surveillance cameras). When the traffic volume is high, a significant overload and enormous cost can be occurred in cellular networks. Thus, this kind of M2M services had better use TVWS with geo-location database CR approach, after the ecosystem for cognitive use of TVWS becomes developed.

# 7 Spectrum auctions with whitespace-augmented spectrum pools

Cognitive radio technology was investigated in the QUASAR project mainly as the enabling technology for the opportunistic secondary spectrum access. In this model a cognitive radio acts as a spectrum scavenger. It uses sensing and/or geo-location databases techniques to identify unused licenced spectrum, the so-called white spaces, and then operates in these spectrum at times/locations where/when it is not used by incumbent systems without the need of a licence. The cognitive radio may use the spectrum either on a strict not-to-interfere basis or on an easement basis, which allows secondary transmissions as long as they are below some acceptable interference cap.

However, in addition to opportunistic spectrum access which is more suited to indoor/WiFi-like usage, the availability of technology and changes to regulations are enabling other possible options to secondary spectrum sharing, which could be more suitable to certain use cases, or actors, for example when there is need for secondary spectrum availability in order to justify operator's long-term investment in infrastructure.

The recognition for need for (and value of) such alternatives approaches to secondary spectrum sharing has become more widespread recently. This has been highlighted for example in the recently released study "Perspectives on the value of shared spectrum access", for the European Commission, which was released in April 2012 [Shared Spectrum].

One recently proposed alternative to opportunistic spectrum access, is the so-called Authorised Shared Access (ASA) approach, which has been put forward jointly by Qualcomm and Nokia. Unlike opportunistic spectrum access which offers as somewhat revolutionary solution to the current spectrum scarcity problem, resulting from static the authorized shared access approach is an evolutionary authorization scheme.

In this approach cognitive radio techniques, such as sensing and geo-location databases enables shared access (which could be either on a secondary or primary basis) of licensed spectrum subject to authorised rights of use. An attractive feature of this approach is that it that it can guarantee predictable spectrum availability, which is not the case with opportunistic access, hence ensuring quality of service. Just like opportunistic spectrum access, different dimensions of spectrum could be used for sharing, i.e. location, time, frequency, and even code. A somewhat similar approach to ASA, called Soft-licencing, is proposed and researched in the QUSAR project [KAWADE].

Both the ASA and the Soft-licensing approach can be considered as an extension of the current regulatory Command & Control spectrum allocation model to accommodate in a controlled manner for secondary use of spectrum. On the other hand, the opening of unused spectrum for sharing also opens the possibility for secondary spectrum sharing via market mechanisms, and in particular via secondary auctions.

The use of spectrum auctions may be very helpful in the pursuit of making secondary spectrum sharing an attractive option to the "mainstream" wireless industry, such as mobile operators because it offers the opportunity of exclusive access rights while at the same time result also in efficient use of secondary spectrum since it is driven by market mechanism. Furthermore, the use of secondary auctions can generate revenue for licence holder, hence creating incentives for sharing, which is lacking in opportunistic access. Finally, regulators such as Ofcom are already allowing secondary trading of spectrum so from a regulatory perspective this option is already possible, at least in some European countries. The main intention is to make spectrum available to those entities that can make most use of it. This flexibility implies that if the supply of spectrum exceeds the demand, no requester should remain underserved. To define a fair and equal base for the competition between stakeholders and discourage opportunistic market behaviour, methods need to be put in place that can balance between the parties and are robust against anti-competitive behaviour.

Spectrum auctions have become a prominent market mechanism to allocate (newly freed) spectrum resources, in particular in the highly competitive mobile industry. In the current licensing regime though, licenses are assigned to operators once spectrum becomes available and the duration of such licenses is chosen to last for a comparably long period of between 5-20 years. This procedure shows some drawbacks regarding the flexibility that is required if the demand of spectrum further increases. A semi-static allocation will potentially result in dissatisfaction because spectrum resources may remain unused that could otherwise benefit the operations of market participants with a shortage in own spectrum.

Spectrum auctions are in this scenario not the only means (other could be to implement simple contractual agreements) but are beneficial if the transaction costs for complex multi-lateral negotiations become prohibitive for spectrum trading to be implemented. The creation of entities that act on behalf of the spectrum license holders, collect scarce spectrum from multiple license holders, "repack" spectrum into the most practical quantities and act as a central market place can improve the efficiency of spectrum distribution and be a leverage for better spectral efficiency.

In this section we propose an approach to secondary spectrum sharing which takes place through a new business entity. All secondary spectrum transactions are conducted through this entity which allocates spectrum through an auction mechanism to potentially competing parties. We investigate how robust and efficient this mechanism is in a heterogeneous market environment with volatile demands. The models we developed in the QUASAR project integrate the notion of a type-dependent utility for spectrum resources.

We will investigate the effects of different configurations of a pool-based spectrum market that employs spectrum auctions for the assignment of spectrum to operators. We focus on the effect the duration of a license has on the outcome of the auctions in terms of different metrics such as the achieved price, the allocative efficiency and fairness. As a baseline we use the current configuration regarding the number of market participants and types of operations from the German PCS market. The system model we develop is based on the rational agent paradigm. This modelling approach allows us to include different types of market participants such as classical mobile network operators and virtual network operators, expressed by different utility functions, into the study.

## 7.1 Analysis description

### 7.1.1 Spectrum partitioning

Traditional means of spectrum allotment build on the partitioning of spectrum into frequency bands, which are offered for individual licensing through a country's regulator. A frequency band is bound to a certain type of technology, or lately only to a certain type of service. The bandwidth of a frequency band varies between the different operational uses. In recent spectrum auctions, licenses were auctioned off that partitioned the free band into chunks large enough to provide for a particular configuration of a wireless technology. For example, in the German auction of spectrum resulting from the digital switchover in April 2010, frequency bands of 5 MHz each with blocks for up- and downlink communication to carry $4^{th}$ generation mobile services were chosen as the atomic unit of distribution.

A more flexible spectrum allocation will require having the smallest tradable unit redefined that can be retrieved from the spectrum pool. In general, three dimensions of spectrum can build the base for such atomicity: In the spatial domain, regulators may define geographic limits to the validity of a license. Most regular licenses are currently issued for an entire country. With smaller regions of licensing, operators may retrieve additional spectrum in areas of high demand. Examples of such short-term peak demands are large sport events or concerts that gather thousands of people for a short period of time. The technological problems of interference avoidance between adjacent areas may pose a serious challenge to this division. Hence, the pure spatial division may become impractical. Another type of spectrum partitioning is to introduce some kind of time-sharing between operators for a particular frequency band. This approach is not recommended due to the availability requirements for certain types of services.

In the following, we therefore resume to the third type of partitioning that divides the frequency band into smaller bandwidth unit, called "Basic Bandwidth Units" (BBU). The size of a single BBU depends on the different factors, which will be discussed only briefly in this section: Technological and economic viability are the main determinants of the lower boundary to the BBU size. If a communication through a standard wireless technology can commence only with a certain minimum bandwidth, this bandwidth sets the minimum amount of spectrum an operator may be willing to retrieve in the market. For this study, we can assume that a channel size of 200kHz, which resembles the size of a single voice channel in 2G wireless networks. In general, no upper boundary exists to BBU sizes, but given the overall finiteness of spectrum in the spectrum pool, it is infeasible to create large BBUs due to the immanent quantization error that occurs if only few market participants can retrieve any spectrum.

### 7.1.2 Market participants

In today's mobile industry, two types of players have emerged as service providers for mobile voice and data services. Besides traditional mobile network operators (MNO), new mobile virtual operators (MVNO) have been established that significantly differ from their counterparts.

Mobile network operators are distinguished by operating their own network infrastructure, including base station installations and a backbone network to connect between mobile devices and/or fixed lines. Cost driver to the operations of a MNO are the costs for deployment, maintenance, energy and rents for the hardware, while variable costs for the operations, e.g. to transmit data between devices, play only a minor role. MVNOs on the other hand do not own any larger infrastructure themselves and instead need to rent services and components from the established MNOs. Variable costs are significantly higher, but more flexibility is given by the possibility of contractual adjustment. This symbiosis is sufficient as long as the MNOs can resell excess spectrum to their client-MVNOs. With increasing spectrum demand by the MNOs own customer base, this system may not be viable anymore.

*Mobile network operators (MNOs)*

For estimating the behaviour of MNOs and MVNOs in the pool-based spectrum market, we need to build a model that captures the differences between these two players in a tangible way. As noted earlier, the cost structure of the players is a metric that influences how the players may interact in a spectrum market. The utility function for spectrum ownership is delimited by certain economic elements that relate to the profit an operator may achieve out of the operations. For this purpose, we specify first the cost structure of the MNOs as

$$C_{MNO}(r) = C_{fix,MNO} + C_{var,MNO}(r),$$

i.e. the costs are composed of fixed costs for owning and maintaining the network infrastructure and variable costs for each BBU $r$ that is served to the customers. With the introduction of a flexible spectrum regulations, the fixed costs will be lowered due to a. the lower requirements for keeping a large spectrum inventory and b. the lower pressure during spectrum auctions to retrieve spectrum (avoidance of opportunistic costs). On the other hand, MNOs will need to buy spectrum from the market. We therefore extend the traditional cost structure to

$$C_{MNO}(r) = C_{fix,MNO} + r \times C_{service} + P_{purchase}(r).$$

This new form implies that the per-BBU marginal costs are a constant, $C_{service}$, and the purchase price for spectrum depends on the requested amount of spectrum and the outcome of the spectrum auctions.

Defining the costs by the amount of spectrum that is required is contrary to how costs calculations are normally conducted. Customers are in general neither charged by the bandwidth, nor do data plans of operators guarantee a certain spectrum for the communication. Instead, the provided data rate is of main interest to the customers as it resembles the users' utility. For this reason, a mapping functions needs to be defined between the required bandwidth and the achievable data rate. This function primarily depends on the technology used. One immediate advantage of including technology-efficiency measures into the operator model is that improvements in technology are reimbursed for by lower bandwidth requirements. We define the simplified technology-leverage function as

$$Q(r) = T_0 \times r - T_{overhead} ,$$

where the technology-dependent overhead $T_{overhead}$ (in kbps) lowers the achievable data rate Q. For simplicity, we assume that $T_{overhead} = T_0$, which is true for a cellular network with a single BBU-sized signaling channel.

*Mobile Virtual Network Operators (MVNOs)*

While current MVNOs rent and resell services from MNOs, future configurations of the mobile industry market may allow the emergence of new types of companies that will only offer infrastructure to MVNOs without offering services to end customers. These mobile virtual network enablers (MVNE) will support the liberalization of mobile markets and may become an important element of the strategy of regulators to increase competition. We include MVNE-type of companies as a passive element for technology provisioning. This allows us to separate the cost structure of the MVNOs from the revenues of the MNOs. MVNEs are modelled as non-profit-oriented entities that will provide infrastructure to MVNOs (without the associated spectrum) at the net cost price. The MVNO cost structure hence becomes

$$C_{MVNO}(r) = C_{fix,MVNO} + r \times (C_{service} + C_{fee}) + P_{purchase}(r),$$

with an additional cost component that is the fee the MVNO needs to pay to the MVNE for its services. The fixed costs of a MVNO are assumed to be considerably lower than those of a MNO.

*Profit as an operator's utility function*

The ultimate target of the operators is to maximize their profits. Therefore it is legitimate to assume the utility function of an operator to be identical to its profit function (at least in the short term). For MVNOs and MNOs alike, the revenue function is

$$R(Q(r)) = R_{fix} + Q(r) \times P_{sell}(Q(r)).$$

Customers are not likely to pay the same additional amount for the same increase in data rate for a small-scale status quo compared to an already existing large data rate. We can therefore assume that the marginal revenues from selling additional spectrum are diminishing. An exemplified revenue function that takes this into account is

$$R(Q(r)) = R_{fix} + Q(r) \times A/\sqrt{r},$$

with a multiplier A that normalizes the revenue function towards an average price within the scale of all possible BBUs in the spectrum pool. The marginal profit, derivative of the difference between revenues and costs, becomes

$$MP_{MNO}(r) = A \times ((r-1)/ \sqrt{r} - (r-2)/ \sqrt{(r-1)}) - C_{service} \text{ for } r > 1,$$

$$MP_{MVNO}(r) = A \times ((r-1)/ \sqrt{r} - (r-2)/ \sqrt{(r-1)}) - C_{service} - C_{fee} \text{ for } r > 1.$$

Note at this point, that the difference in marginal profits shows a fixed offset between MNOs and MVNOs determined by the MVNE service fee.

*User-driven spectrum demand model*

Bandwidth requirements vary over the day given the number of users that are active and the type of service they request from the operator. Data services are particularly versatile to model, because activity is usually bursty due to the short-termed requests of downloading web content or updating the status of an e-mail inbox. For this reason, we model the cumulative demand of all customers of a single operator as an exponential distribution

$$f(Q(r)) = \lambda * e^{\lambda Q(r)},$$

that is sufficient to model a large number of users requesting a fixed bandwidth at independently distributed request times. The rate parameter λ needs to be determined in advance to fit the usage persistency of the group of customers. We approximate the parameter by deducting it from the existing distribution of spectrum to operators in the current mobile market. We assume that the spectrum inventory reflects the targeted user satisfaction level, i.e. probability that a user can be assigned the bandwidth he requests. Inversion of the cumulative distribution function yields in

$$\lambda \approx (4.6 - \ln(100\text{-}v))/Q(r),$$

for a given percentage of satisfaction level of v. Setting r equal to the current spectrum inventory returns the expected request rate λ.

## 7.2 MU-Vickrey spectrum auction model

The operators' behaviour in a spectrum auction is determined by three main factors.

- The operator's knowledge about spectrum demand within the duration of the spectrum license
- The achievable profit from providing capacity to the customers
- The existing spectrum inventory of the operator

In our model we assume that the operators have coarse-grained knowledge on the spectrum demand within the license duration time and perfect forward prediction capabilities for the current demand. This limitation allows operators to only know the average demand of spectrum required when bidding in a spectrum auction. As the license durations become shorter, the a-priori knowledge will approach the perfect demand estimation.

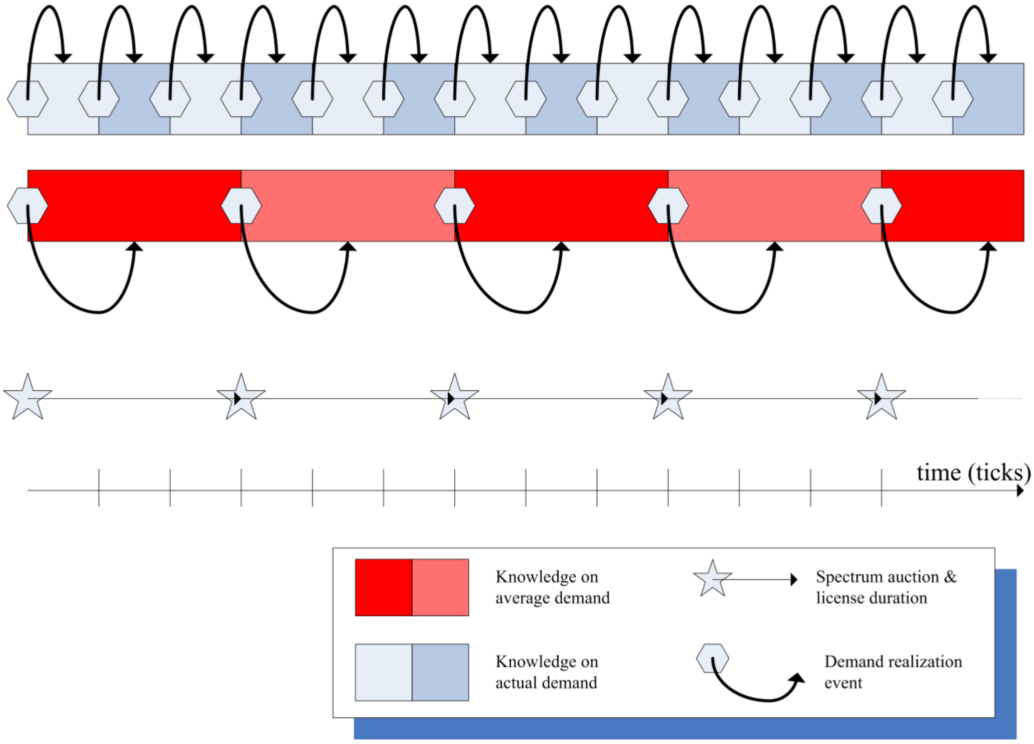



Figure 7-1: Demand knowledge assumptions for operators in short-termed spectrum auctions.

The auction mechanism determines how the operators will exploit this knowledge to minimize the costs of acquiring spectrum while keeping the risk of dissatisfying customers due to a lack of spectrum low. We found that Multi-Unit (MU) Vickrey auctions are best suited to distribute BBUs among operators while having the freedom to express spectrum demand and valuation in a fine-grained manner. Each operator i in this auction mechanism submits a bid vector $_{Bi}$ = | $b_{i,1}$ $b_{i,2}$ .. $b_{i,n}$ | where $b_{i,m}$ represents the amount the operator is willing to pay for the m:th BBU. The auctioneer naturally assigns BBUs to the highest paying bidders until exhaustion of the spectrum pool. Contrary to other auction types where the bidder pays the bids he plays, in the MU-Vickrey auction the bidder pays the k highest losing bids of the defeated bidders for those k BBUs that were distributed.

The Vickrey auction mechanism is advantageous for several reasons

- The weakly dominant strategy of the auction is to bid the true valuation of spectrum units, i.e. the marginal profit gains achievable if the spectrum is assigned. Under the assumption of full contract freedom between operators and customers this results in a constellation where those customers that value spectrum most will with a high likeliness be assigned some from the spectrum pool.
- The auction mechanism does not skim off profits from the operators. Since in general the due payment to the auctioneer, e.g. the spectrum regulator, is lower than the profit margin, operators are still capable of deriving profits from their services.
- Since there is no incentive of bidding more than the true valuation of spectrum in the run, the mechanism is stable against collusive behaviour.

## 7.3 License duration effects: Prices, allocative efficiency and fairness

| | |
|---|---|
| BBU size | 200 kHz |
| Spectral efficiency | 384 kb/s/BBU |
| Operator spectrum inventory | 1500 BBUs (equally distributed among MNOs) |
| Spectrum pool size | 1500 BBUs (3000 BBUs for abundance case) |
| Number of MNOs | 4 |
| Number of MVNOs | 50 |
| Spectrum demand rate MNO | $2.08 * 10^{-5}$ (1/kbps) |
| Spectrum demand rate MVNO (assuming equal market share MNO,MVNO) | $1.37 * 10^{-4}$ (1/kbps) |
| Operational costs service | 30% of fixed-cost deducted revenue margin |
| Operational costs MVNE fees | 10% of fixed-cost deducted revenue margin |
| Per-BBU achievable revenues | 200 MU |

Figure 7-2: Simulation configuration.

In Figure 7-2 the configuration for the study of license duration effects is shown. We have aligned the parameters to fit a larger European market, e.g. the German PCS market. Technical parameters were derived from the specification of the traditional GSM mobile telephony system with extensions to the data services through EGPRS.

Four different scenarios are studied with different levels of freedom of trading and persistency of spectrum assignment to account for the possibility of different migration paths of the European regulatory system. Scenario 1 (S1) models the pooling of new spectrum that has become available through the expiration of spectrum licenses. The original configuration of the market with large MNOs as the only beneficiaries of licenses remains unchanged. The spectrum pool contains 1500 BBUs, approximately the size that is freed by the digital dividend of the TV broadcasting services.

Scenario 2 (S2) extends the first scenario with the possibility of re-trading spectrum of the MNOs. MVNOs that have no spectrum resources on their own can thus acquire spectrum from two sources. For reasons of symmetry, the MNOs are forced to put excess spectrum into the spectrum pool without compensation. Both, MNOs with demand beyond their inventory and MVNOs can acquire the spectrum. Re-traded spectrum returns to the original licensee after each round.
Scenario 3 (S3) is a long-term option for spectrum pooling. Once the original licenses are expired, they are not reallocated but become part of the spectrum pool. All operators hence need to compete for spectrum. MNOs and MVNOs differ for that they have different customer base sizes, potentially putting the MVNOs under more pressure due to the competition with the significantly larger MNOs. We model this scenario for two cases, one is the spectrum scarcity (S3) where only 3000 BBUs are available in total, one is the abundance case with 4500 BBUs (S4).

### 7.3.1 Development of average prices

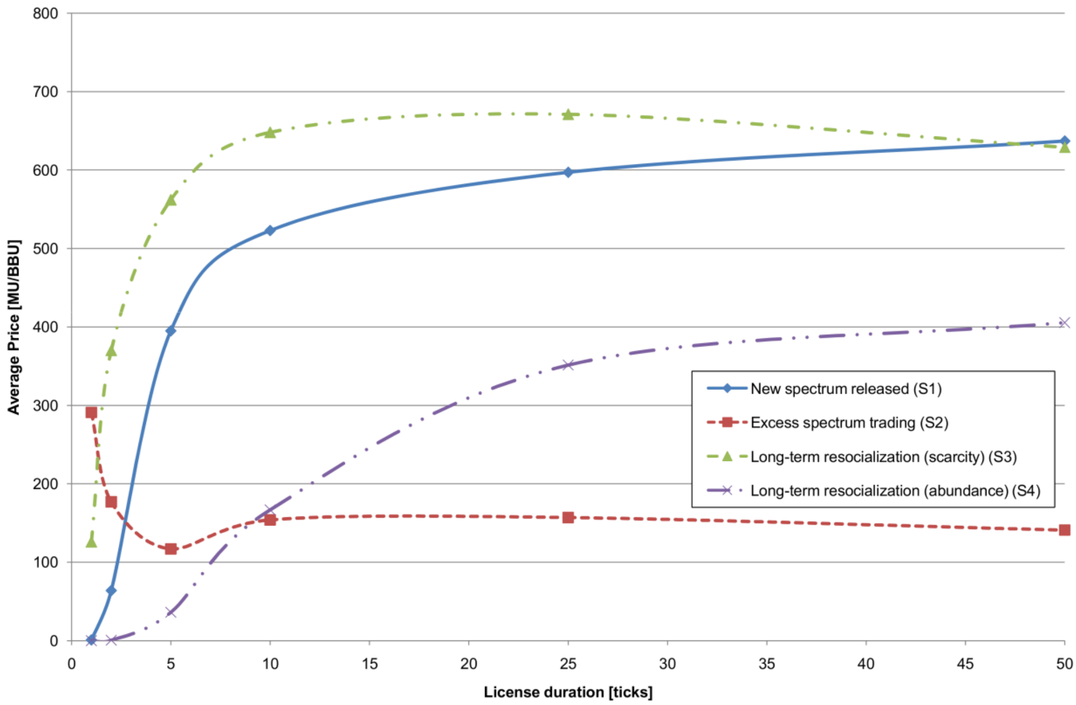



Figure 7-3: Average market price of BBU.

Short license durations allow operators to acquire only as much spectrum as required at the particular point in time to fulfil their customer demands. If the license duration is prolonged, a certain level of overprovision becomes necessary since periods of higher demand within the license duration need to be accounted for as well.
All scenario outcomes show the same pattern for extended license duration times, i.e. the prices approach a constant value that depends on the freedom of re-trading. Scenario 2, which allows most freedom in acquiring spectrum at a later stage, converges towards the lowest price due to the anticipation of the possibility to reacquire spectrum for covering short-term high demands. At the same time, this scenario shows significant competition in short-term licenses due to the harsh competition between MVNOs.
Lowest competition and consequently lowest average prices are achieved if the spectrum pool is only rarely used by the MNOs and mostly MVNOs require it due to the absence of a spectrum inventory. Here, the MVNO demand is easily fulfilled and market prices approach zero. A similar observation is made from the long-term resocialization case with spectrum scarcity, where MNOs with lower variable costs can first fulfil their demand. MVNOs with higher costs and no possibilities to pay higher prices than the MNOs are forced out of the market in this case.

### 7.3.2 Unallocated (excess) spectrum

As a measure of inefficiency we now study the excess spectrum the different types of operators have on average for the different scenarios.

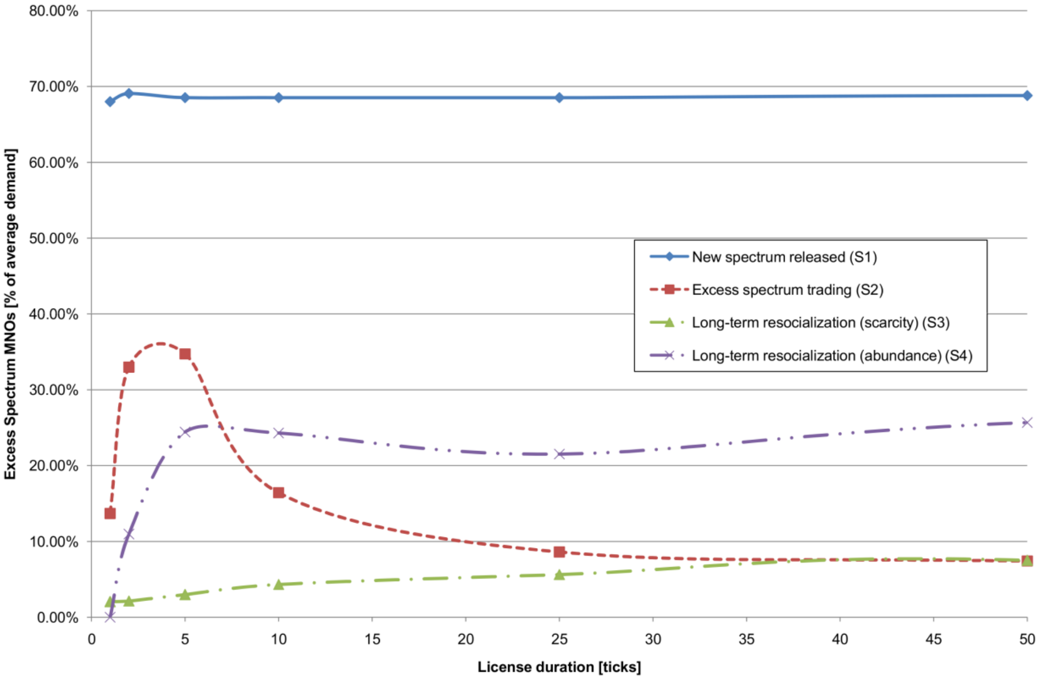



Figure 7-4: Excess spectrum of MNOs

Figure 7.4 depicts the excess spectrum of MNOs. Naturally, the simplest scenario S1 shows the highest inefficiencies because the MNOs only occasionally exhaust their resources. The other extreme case occurs if there exists a scarcity in spectrum and the MNOs have to acquire spectrum from the market at any time. Almost no excess spectrum can be observed in this case.

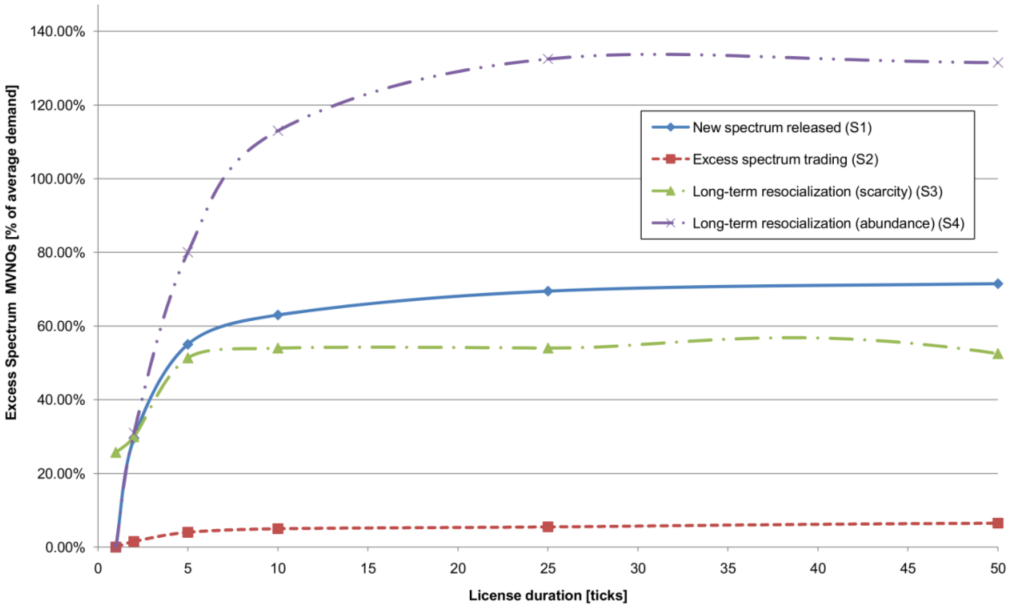



Figure 7-5: Excess spectrum of MVNOs.

MVNOs operate most efficiently when excess spectrum of MNOs becomes available in the market. Surprisingly, Figure 7-5 shows that in case mostly MVNOs compete in the market (S1) they are assigned more spectrum than necessary, pointing to an abundance of spectrum in the spectrum pool. This abundance becomes more clearly visible in case S4, where more spectrum is in the pool than required by the sum of all operators.

### 7.3.3 Unmet demand

To complete the picture of allocative efficiency, the unmet demand of the different operators is studied.

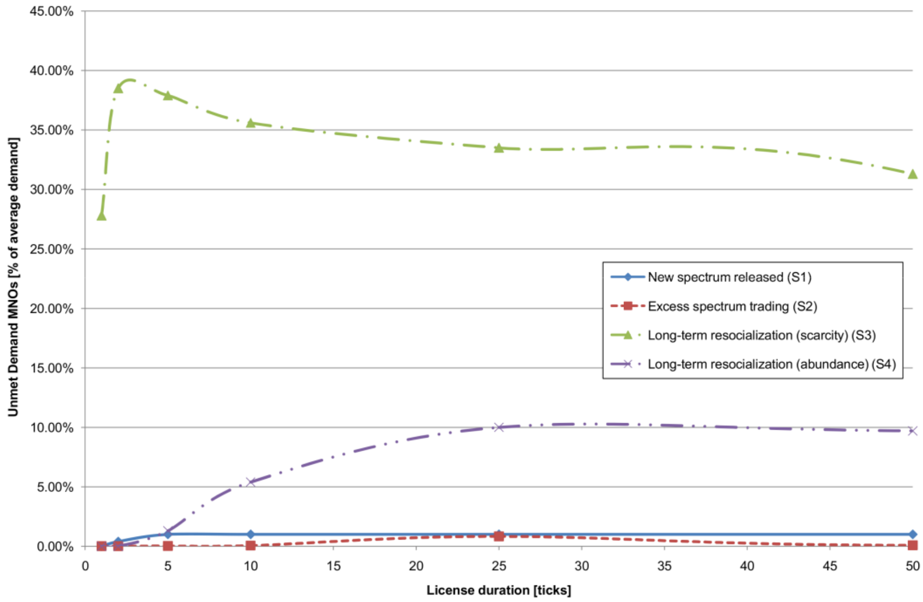



Figure 7-6: Precentage of Unmet demand of MNOs.

Highest satisfaction of MNO customers is achieved if the MNOs are allowed to keep their spectrum inventory (Case S1 and S2 in Figure 7-6). For MNOs the demand of offering excess spectrum through the spectrum pool on average improves their situation even further, because they can acquire spectrum from the pool that stems either from the general inventory or from other MNOs that are underutilizing theirs. A strong drawback in the eyes of the MNOs is the re-socialization, i.e. the return of all existing spectrum into the pool, in case of spectrum scarcity. Though the MNOs are capable of outbidding the smaller MVNOs, the marginal diminishing returns make them leave a certain amount of users unserved. This situation occurs once the marginal gains from more spectrum in the larger-quantity MNOs is lower than the marginal gains from the MVNOs.

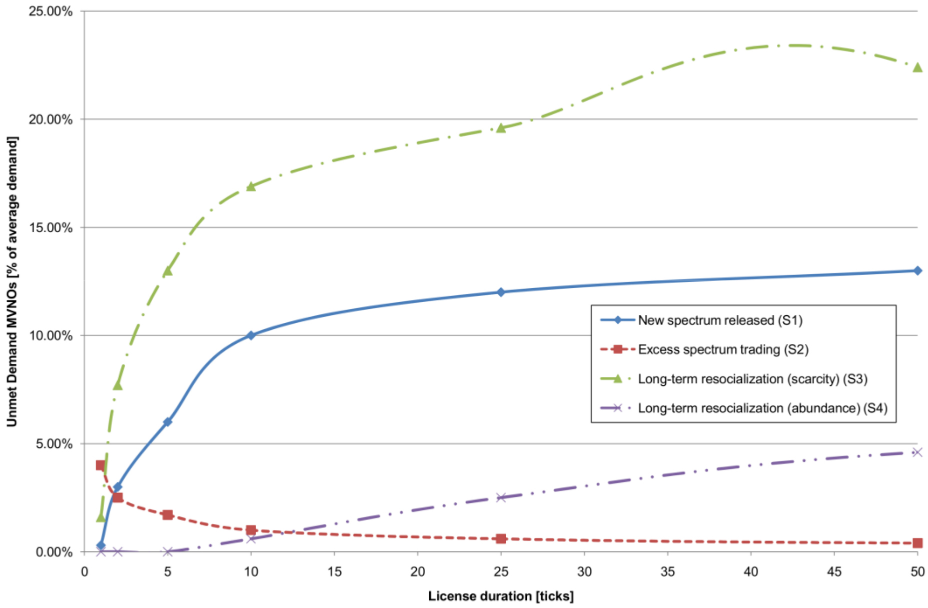



Figure 7-7: Percentage of unmet demand of MVNOs.

For MVNOs the force of re-trading from the MNOs is satisfying their needs better than a similar case where only the fixed pooled spectrum is made available. As shown in Figure 7-7, the unmet demand converges towards approximately 14% if this is the only source of spectrum. Contrarily, the excess spectrum trading will results in almost perfect satisfaction of the user demands. Spectrum scarcity in a re-socialization scenario does not equally hurt the MVNO customers.

### 7.3.4 Conclusions

Shorter license durations and more freedom to re-trade spectrum lower the unmet demand of MNOs and MVNOs. The important design parameter of a spectrum auction is how often and to what extend spectrum can be traded between market participants. The results from an evaluation of different levels of market freedom have shown the following.

MNOs can improve their customer satisfaction even if they are forced to put excess spectrum into a spectrum pool. The additional costs of renting infrastructure hampers market competition for MVNOs due to their lower profit margins. This does not include the fixed costs depreciation of MNOs for their existing infrastructure.

There is an incentive of MNOs to underprovision spectrum due to the diminishing revenues, resulting in a higher level of dissatisfaction. Shorter license durations are beneficial in terms of efficiency as well as average prices. The only exception to this rule is the case of forced excess spectrum trading where the average prices for very short license durations are higher but decline fast.

# 8 Summary and conclusions

This report provides initial findings on the business feasibility of services based of secondary access of spectrum. The analysis focuses on two of the QUASAR service scenarios *Cellular use of TV white space (TVWS)* and *Cognitive machine-to-machine scenarios using cellular bands*. For wireless access in indoor locations we also discuss the scenarios *WiFi-like use of White Spaces* and *Indoor Broadband using Aeronautical band.*

In the report we have provided three different types of investigations where we analyse the business feasibility of systems using TVWS for mobile broadband access services. In the first place it may look like that the different results are somewhat contradicting but the conclusions heavily depend on the working assumptions. This is related to what actor that provides the service and the resources that the actor has – or do not have, i.e. what kinds of investments that needs to be done. Hence, this conclusion section includes general findings based on analysis of cost structure and company assets followed by conclusions for different business scenarios.

In this conclusion section we first highlight the need to consider the multitude of scenarios and assumption. Next, we summarize the findings on use of TVWS compared to addition of more licensed spectrum. The business feasibility analysis for the scenarios *Cellular use of TV white space and Cognitive machine-to-machine scenarios* are summarized in separate sections. Finally, we comment on the potential availability of cognitive radio equipment.

## 8.1 A multitude of multitudes

One main finding from this analysis is the need to consider many aspects and scenarios. The results depend heavily on the working assumptions and the perspective of the analysis. It turns out that the QUASAR service scenarios cannot be seen as one specific scenario with well-defined properties. The techno-economic business feasibility depends on a number of aspects. Hence, each service scenario can consist of multiple sub-scenarios. The business feasibility is not an inherent property of any type secondary use or the type of primary spectrum; instead the business feasibility depends on specific business cases. Hence, we will look into a number of different sub-scenarios characterized by:

- The availability of spectrum for secondary use
- The type of service intended for secondary use
- The demand and willingness to pay for the service
- The type of radio access technology used for the specific service
- The cost structure for network deployment options
- The cost for spectrum licenses
- If the secondary use of spectrum is the only resources or a complement
- The characteristics of the actor providing the service

## 8.2 Use of TVWS compared to addition of licensed spectrum

For existing mobile operators allocation of more licensed spectrum (e.g. a 2$^{nd}$ digital dividend) is in most cases more beneficial than use of TVWS for provisioning of mobile broadband services. This is illustrated by the analysis of a macro cellular network operating in Germany. Based on estimated availability and usefulness of TVWS channels it is found that it would be better for mobile operators if regulators were to go for a second digital dividend rather than allowing use of TVWS opportunities. In the case of existing fixed line operators, however, allowing the use of TVWS opportunities, and possibly shared use of second digital dividend, is an attractive option.

## 8.3 Business feasibility of TVWS for mobile broadband

Here we consider cases where addition of more licensed spectrum is not an option. The results are presented for different deployment and actor scenarios.

**General findings based on cost structure**

The analysis shows that the business feasibility depends on what kind of actor that provides the service and the amount of company assets and resources that exist (i.e. that can be re-used) or need to be acquired (i.e. require investments).

New actors that will use TVWS as the only resources will have much higher costs than an existing mobile operator since they have to invest in new infrastructure. The situation is even worse if they need to build up a customer base, customer care and billing platforms.

Existing mobile operators with licensed spectrum and already deployed mobile networks can use TVWS and cognitive radio (CR) as an alternative to deployment of new base station sites when capacity upgrades are needed. Although CR equipment has different cost-capacity characteristics than commercial LTE base stations, the addition of CR to exiting sites may still be more cost efficient than deployment of new sites using licensed spectrum.

For actors without any licensed spectrum for mobile broadband (e.g. fixed line operators or broadcasting companies) there may be good business cases based on TVWS when existing infrastructure like transmission, equipment rooms, power supply, etc. can be re-used. The BT analysis of the case in the UK is a good example.

For indoor systems secondary access of spectrum can be used as a replacement or a complement to licensed and unlicensed operation. The business feasibility depends both on what type of business cases (offloading to mobile operators, roaming between operators or hot spot services offered to end-users) and on what actors that provides the service. Again it is the amount of resources that need to be acquired (i.e. costs) that are different for different types of services and the actor that provide the service.

**Business feasibility for different mobile broadband cases**

*Rural areas with "low" population density*

Here we consider rural areas in countries like Sweden and Finland with very low population densities (< 20 persons per km$^2$) and large cells implying a coverage limited system. Here there is no need for use of TVWS since there is no shortage of licensed spectrum. If capacity is limited a first action by operators would be to share spectrum and sites.

*Rural areas with "higher" population density*

In countries like the UK and Germany the population density is higher and around the limit defined by EU for rural areas (150 persons per km$^2$). For current assumptions on user penetration, market share of operators and deployment strategies these scenarios are capacity limited. Use of TVWS is beneficial for actors with an existing infrastructure:

- Existing mobile networks operators with licensed spectrum that would like to increase capacity without building new base stations sites
- Actors like fixed line operators that can re-use existing infrastructure to such an extent that the deployment of new CR based base stations are reasonable from a cost perspective. This requires prioritized usage of TVWS

*Macro deployment in urban areas*

In this case we consider urban areas with high population densities and expected low availability of available TVWS channels. Here we can identify two cases.

For *existing mobile operators* there is a potential to use the available TVWS spectrum. For this type of actor TVWS is not the only resource, it is considered as a complement to the use of licensed spectrum. Similar to the rural cases above TVWS can be used to increase capacity without building new base stations sites, hence providing cost benefits. This may be of value in areas where there is difficult/impossible to build new sites.

For *new actors providing mobile broadband services* the situation is the opposite, i.e., the business case does not look too promising. TVWS is the *only* resource, hence capacity and quality may be low or unreliable. Further, the new actor needs to build a new infrastructure and deploy new sites. Even if the CR may have good cost-capacity performance the costs for deploying sites are too high.

*Indoor deployment*

In this scenario we have a number of cases including many actors where TV or radar bands may be used as replacement or a complement to licensed and unlicensed bands.

*Mobile operators* can use TVWS to add capacity to the own cellular network and also to offer the indoor capacity to other operators using some form of national roaming.

*Facility owners or hot spot (WiFi) operators* can offer indoor capacity on a wholesale basis as offloading services to operators using TVWS. Two different types of access can be identified: Roaming type of access requiring core network capabilities and "hosting" of access points belonging to operators as part of the operator network. Offering indoor capacity direct to business users or consumers would be challenging for two reasons. This kind of service can be provided already using WiFi or unlicensed cellular bands and new actors need to invest in customer acquisition, CRM, billing platforms etc.

## 8.4 **Business feasibility for M2M services**

Here we consider M2M devices that utilize TVWS with a geo-location database.

*Existing mobile operators* with licensed spectrum can use TVWS as additional resources to provide M2M services. Similar to the macro deployment in urban areas, there is a potential to use TVWS without incurring excessive cost for building base station sites.

*New actors for providing M2M services* are hard to succeed in the CR business with TVWS. New actors do not have any infrastructures for their services; hence they need to invest in building new base station sites for M2M services which incur large costs rendering the business case less valuable. By leasing the infrastructure from existing mobile operators, new actors can provide M2M services in the type of MVNO. However, agreements with legacy operators need to be set up to allow this type of sharing.

M2M services in TVWS still have challenges for the following reasons: The TVWS ecosystem is immature. The regulation is at an early stage and geo-location databases for TVWS are only available in the USA. Some network equipment, chipsets, and devices for TVWS applications are in development, but few solutions have been announced so far.

For the present, the cellular network is expected to be able to offer M2M services, which is called machine-type communication (MTC). With a large number of M2M devices, however, congestion in the radio access network and control signal overhead should be solved. The cognitive M2M in cellular spectrum provides a solution in that the data of each M2M device is collected at a cluster header using CR technique and the cluster header uses the standard cellular system as a backhaul connection. For this type of operation a spectrum sharing agreement between the service provider and the cellular operator holding the spectrum license needs to be arranged. If the license holder itself uses the proposed MTC solution in its own band the proposed solution may be proposed for standardization under the 3GPP umbrella.

# Acronyms

| **Acronym** | **Meaning** |
|---|---|
| CAPEX | Capital Expenditures |
| OPEX | Operating Expenditures |
| NPV | Net Present Value |
| TVWS | TV White Space |
| WSD | White Space Device |

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