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## Conference Paper

# Analysis of business opportunities of secondary use of spectrum: The case of TV white space for mobile broadband access

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22<sup>nd</sup> European Regional ITS Conference  
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**Jan Markendahl and Östen Mäkitalo**

Analysis of business opportunities of secondary use of spectrum  
- The case of TV white space for mobile broadband access

**Abstract**

The introduction of mobile broadband technology, smartphones and dongles has resulted in a tremendous increase of mobile data traffic. Future demand for more capacity can be met by allocation of more bandwidth and new spectrum bands to mobile communication. But spectrum is a scarce resource and allocation of new licensed bands will only partly satisfy the growing demand.

Another possibility is secondary use of spectrum bands which primarily have been allocated for other services, e.g. TV or weather and traffic control radars. The secondary use exploits un-used spectrum in frequency, time or physical location. Such un-used spectrum in the TV bands is called TV white space (TV WS).

In this paper we will focus on the business analysis of “cellular use of TV white spaces” where the service is mobile broadband access. A number of business cases are analyzed where we look into mobile broadband services in rural and urban areas and for indoor use. The service can be provided by a mobile network operator with licensed spectrum or by an operator using TV white spaces only.

The analysis indicates that market entrants will be in a more difficult position than the established actors. New operators need to invest in networks, platforms, marketing and customers. Promising business cases are presented for existing mobile operators that use TV WS as complement for capacity expansion in urban areas and for local operators (e.g. facility owners) that will use TV WS and own indoor infrastructure in order to offer “indoor” capacity to mobile operators

**JEL codes: L960, L50, 013**

**Keywords:** Mobile broadband networks, spectrum allocation, cost structure analysis, spectrum, business case network deployment strategies, telecommunications, economic development of natural resources, regulation and industrial policy

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# 1. Introduction

Wireless access to an increasing number of new and existing services has become a major trend in just a few years. In addition to the increased requirement of capacity for communication services and new applications completely new areas have become of interest such as use in the process industry, governmental services, education, local and regional operator services, M2M communication etc. We can foresee a society where everything is on-line, people as well as things. Thus the number of connected devices is expected to increase dramatically possibly to 50 billions.

In the case a very large part of the society is run on-line leading to new requirements on capacity, coverage, reliability and availability. Most of the new requirements are easier to meet with more bandwidth and use of new spectrum bands. More spectrum has been available for wireless broadband services by allocation of the 2,6 GHz and 800 MHz bands, and in some countries auctions have taken place.

Another possibility is secondary use of spectrum which primarily has been allocated for other applications, e.g. TV or radar. Several hundreds of MHz belongs to those categories. The secondary use exploits un-used spectrum in frequency, time or physical location. Such un-used spectrum in the TV bands is called TV white space (TV WS). To exploit such possibilities new technology has to be developed and also new regulation. Secondary use of spectrum has been identified as an opportunity by regulators and the research community. Statement by FCC Commissioner Meredith Attwell Baker, 2009<sup>1</sup>:

*"We need to find more spectrum, I think we need to leverage the spectrum that exists currently more efficiently " "I'm talking about more spectrum sharing between private and federal "*

The director Wireless@KTH of Jens Zander comments on the use of spectrum 2011<sup>2</sup>:

*" it will at that point become very hard to motivate to use 2-300 MHz of prime spectrum for mobile use to serve a few percent of the population receiving TV "over the air" .."*

Secondary use of spectrum must not cause interference to primary users. Limitations both on secondary and primary use can be minimized by use of new technologies such as cognitive radio (CR), software defined radio (SDR), dynamic spectrum access (DSA) etc. In ongoing research initiatives such as COST-TERRA<sup>3</sup> and the FP7 project Quasar<sup>4</sup> these questions are studied. In Quasar also the business opportunities are evaluated.

In this paper we will present an initial business analysis of mobile broadband access services, i.e. one type of cellular use, using TV white space as the spectrum resource.

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<sup>1</sup> <http://spectrumbridge.blogspot.com/2010/02/opening-of-secondary-spectrum-market.html>

<sup>2</sup> <http://www.theunwiredpeople.com/blog/spectrum/132>

<sup>3</sup> <http://www.cost-terra.org/> (COST stands for "European Cooperation in Science and Technology")

<sup>4</sup> <http://www.quasarspectrum.eu/>

## 2. Problem description

### Technical and business challenges

Secondary use of spectrum is associated with a number of technical problems. First, the available frequency bands need to be identified and monitored. Next, the secondary usage needs to be managed in order to avoid interference to the primary user and to handle interference between multiple secondary users that have detected the same “available” frequency band.

An example of spectrum availability is shown in Figure 1. The number of “un-used” TV channels is very low in most part the country. “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. If TV white space is to be used for mobile broadband access there is a difference how it can be used depending on how the mobile broadband network is deployed. 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.

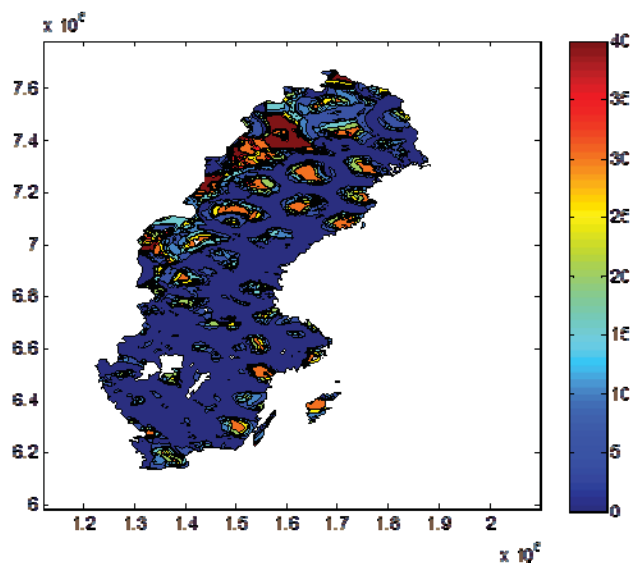


Figure 1 Example of spectrum availability - Number of available TV channels in Sweden (picture from from Quasar deliverable D5.1, 2011)

But the challenges do not only include to find more spectrum or to find technologies in order to “find more spectrum” e.g. for sensing and management of secondary spectrum.

Allocation and use of secondary spectrum also have implications in the business and regulatory domains. New business roles, new actors and new cooperation models will need to be developed since the traditional approach with long term spectrum licenses awarded to few actors is no longer applicable. Hence, the business feasibility of services based on secondary use of spectrum need to be evaluated in business scenarios that also include other actors and cooperation models than those that dominate today's business. Understanding of different business model options and cooperation models are essential in order to design and evaluate new types of policies and regulatory directives.

## **A multitude of scenarios**

In the FP7 project Quasar the need to use different business and services scenarios for evaluation of use of secondary spectrum has been identified. A number of service scenarios have been identified and described (Quasar, 2011).

- Cellular use of TV white spaces
- WiFi-like use of white spaces
- Secondary wireless backhaul
- Secondary spectrum commons in radar band
- Indoor broadband in aeronautical spectrum
- Cognitive Machine-to-Machine

We would like to 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. Our starting point for the analysis is that the business viability not is 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.

In this paper we will focus on “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 analyzed. 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 or by an operator using TV white space only (TVWSO). We will show initial results in order to show what business cases that look promising and should be analyzed further.

At this stage no general analysis applicable to all service scenarios will be used. Instead, the analysis is done using approaches that are using tailor made to the specific service scenarios. In the Quasar project we will assess our own analysis approach and results in order to contribute to the understanding of how business cases built on secondary use of spectrum can be analyzed from a business perspective.

## **Research questions**

The objective and scope of business feasibility analysis in the Quasar project is twofold. First, the business feasibility of all the Quasar service scenarios should be analysed. In addition, the developed analysis methodology should be described and the potential to use it as a common and general framework for business analysis of concepts and scenarios for secondary use of spectrum should be assessed. This can be formulated as two main research questions

- What kinds of business opportunities can be identified for different situations where some kind of business actor makes use of secondary spectrum?
- Is there a common business feasibility analysis "method" or do we need a multitude of case dependent "methods"?

In this paper we will address the first main research question and target our contribution to a specific type of service scenario resulting in two research questions:

- RQ1. What kinds of business cases can be identified when a mobile operator makes use of TV white space spectrum for mobile broadband access services?
- RQ2. What business opportunities can be identified for these business cases?

### 3. Related work and contribution

Regulators and consultancy companies have submitted a number of reports where the value of spectrum for the society, consumers and providers is presented (Europe Economics, 2006), (Marks et al, 2009), (FCC, 2010). The economic value of unlicensed spectrum is discussed in a report supported by Microsoft (Perspective, 2009). An overview of regulatory status and activities for secondary access to TV white spaces is presented in (M. Nekovee, 2011).

The UK regulator Ofcom has invited a number of market actors to respond to consultation by the regulator on secondary use of spectrum. The response has been positive on proposals on cognitive access to the interleaved spectrum<sup>5</sup> and proposals for implementing geolocation-based access to the TV white spaces<sup>6</sup>. Among market players that support these proposals we can find companies like Dell, Google, Hewlett-Packard, LG Electronics, Microsoft, Nokia and Philips.

The value of spectrum for operators can be analyzed by estimation of additional cost or cost savings depending on the amount of allocated spectrum. The basic approach is described in (Marks, et al, 1996) and (Sweet et al, 2002), results using this type of approach can e.g. be found in (Azcoita et al, 2009) and (Mölleryd et al, 2010)

Business aspects for use of secondary spectrum have been discussed by within COST-TERRA, Anker (2011) and Barrie (2011). Business models for use of cognitive pilot channels have been proposed by e.g. Ballon and Delaere (2009).

In the EU FP6 project Ambient Networks business model research was done for markets with a structure similar to the one that can be predicted if services based on secondary usage of spectrum will be deployed. These markets will include existing and new actors taking different types of business roles (existing and new) and also forming new types of value networks (Markendahl et al, 2006). A multitude of scenarios and “commercial use cases” were used in this business analysis (Markendahl, 2006).

In this paper we will not focus on the general value of spectrum for society or on valuation based on savings in network costs. Our contribution is to analyze the potential for specific types of market actors to make profitable business based on the secondary use of spectrum.

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<sup>5</sup><http://stakeholders.ofcom.org.uk/binaries/consultations/cognitive/responses/dgmp.pdf>

<sup>6</sup><http://stakeholders.ofcom.org.uk/binaries/consultations/geolocation/responses/Coalition.pdf>

## **4. Methodology and analysis approach**

### ***General***

At this stage in the project we do not have any general analysis approach that is applicable to all Quasar service scenarios. Instead, the analysis is done using approaches that are using tailor made to the specific sub scenarios and business cases.

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 in the technical design, functionality and, e.g. use and implementation of data bases, spectrum sensing, cognitive pilot channel. We will do the business analysis assuming that all new technology will work as expected. The analysis will be done for specific services making use of secondary spectrum at specific markets. Hence, it is NOT the business opportunity of a specific technical solution or function 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 is no business case although these ideal conditions exist, then there is no need to make a more detailed analysis. On the other hand, if promising business cases should be identified a more refined analysis focused on the aspects that are most uncertain needs to be done.

### ***A multitude of multitudes***

As mentioned above there are a number of aspects that need to be considered for the business feasibility analysis. Hence, we can expect that is not 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, type of cognitive radio and approach for sensing and secondary use of spectrum.
- The type of deployment areas, in the case of mobile broadband access; rural, suburban, urban metro, or in hot spots. Indoor and/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 other 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, is the service already available?

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.

### ***Demand aspects***

For dimensioning of mobile broadband access we define the user demand as the capacity needed per area unit expressed as Mbps per km<sup>2</sup>. 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. 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.

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 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 1 Examples of required capacity as function of number of users and usage level

		Area demand for different usage levels (Mbps /km <sup>2</sup> )		
Geotype	Users per km <sup>2</sup>	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

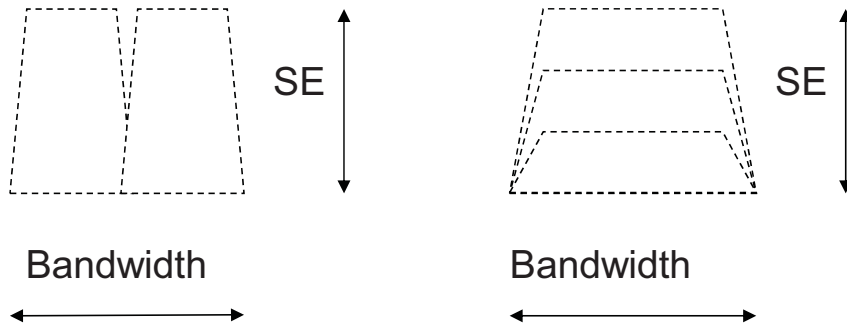


Figure 2 Bandwidth and spectral efficiency

### ***Offered capacity***

The offered capacity for the mobile broadband access service depends on the available bandwidth and the spectral efficiency. The offered capacity in Mbps equals bandwidth (MHz) \* spectral efficiency (bps per Hz), see Figure 2. The bandwidth depends on the number of available TV channels and the spectral efficiency depends on the network topology and the location of the users.

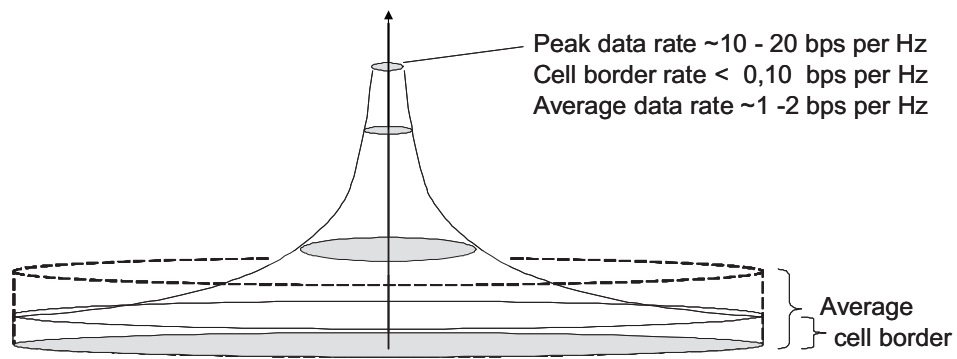


Figure 3 Spectral efficiency target values for LTE

In our estimates we will use average values although we know that the spectral efficiency for MBBA depends on the location of the end-user. In Figure 3 ITU target values are shown for the peak, average and cell border values for LTE. The orders of magnitude of the base station site capacity are illustrated in table 2, assuming a three-sector base station site.

Table 2 Examples of offered 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

### ***Availability of TV white space***

In the Quasar project the number of available TV channels has been estimated for a number of countries. Using a macrocell type of deployment the number of TV channels available for mobile broad band is quite low.

For Sweden very few channels ( $< 5$ ) are available in most parts of the country, see figure 1. Only in some rural areas in northern Sweden more than 20 channels are available, in these areas the demand is very low. For the analysis an average value of available TV channels in an area will be used.

Each TV channel has a bandwidth of approximately 8 MHz, i.e. that 1 and 4 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)

### ***Cost structure analysis***

A high level cost structure modeling and analysis will be used. The cost structure of the radio access network is modeled by using three main components: the radio equipment, the base stations sites and the transmission (Johansson, 2007).

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.

(An ongoing work item in the Quasar project is to make a more detailed cost structure model for the cognitive radio system. In addition to the radio transceivers it also includes 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.)

## 5. Analysis

### *Investigated sub scenarios and business cases*

In this section we will describe the investigated scenarios in terms of offered service, type of deployment, cost structure, demand and competing solutions.

### **The service and the radio access technology**

The “cellular use” of TV white spaces considered in all cases is mobile broadband access (MBBA) 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.

The TV WS could be used as complement to or replacement for spectrum in the 800 and 900 MHz band. We consider use of TV WS by both existing Mobile Network operators (MNOs) with licensed spectrum and by new actors called “TVWS only” operators (TVWSOs).

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, 1-3 TV channels corresponding to a bandwidth of approximately 8 – 24 MHz.

### **Sub scenarios within the service scenario**

We consider four sub scenarios within the service scenario “cellular use of TVWS”

- *Mobile broadband access in urban 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 areas including hot-spots.
- *Mobile broadband access in urban areas provided by “TVWS only” operator*  
A TVWSO (without any own licensed spectrum) will use own infrastructure and using TV WS in order to offer MBBA services in urban areas to consumers.
- *Mobile broadband access in rural areas provided by a “TVWS only” operator*  
A new actor plan to deploy macro cells in order to provide in order to provide cost efficient mobile broadband in rural areas
- *Indoor mobile broadband access provided by local operator.*  
A local indoor operator (e.g. a facility owner) will use TV WS and own indoor infrastructure in order to offer ”indoor” capacity to mobile operators

### ***Analysis of 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 1 we presented examples of the user demand depending on usage level of mobile data and the number of users per area unit. The range of demand in these scenarios, expressed as Mbps per km<sup>2</sup>, can be compared to the offered capacity using bandwidth corresponding to one or four TV channels, see table 3. We have assumed deployment scenarios where the cell size differ an order of magnitude when it comes to coverage area. For the capacity estimates we assume three-sector sites and an average spectral efficiency of 1 bps per Hz.

Table 3 Examples of offered capacity per area unit assuming different cell sizes and bandwidth.

eotype	Users/km <sup>2</sup>	Demand(Mbps/km <sup>2</sup> ) 1 – 10 GB/month	Cell area(km <sup>2</sup> ) [radius (km)]	Capacity(Mbps/ km <sup>2</sup> )	
				8 MHz	32 MHz
Rural	10	0,1 - 1,0	100 [5,6]	0,24	0,96
Suburban	100	1,0 – 10	10 [1,8]	2,4	9,6
Urban	1000	10 – 100	1 [0,56]	24	96
Metro	10000	100 – 1000	0,1 [0,18]	240	960

The comparison indicates that the current demand levels 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. 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.

### ***Analysis of cost structure and network costs***

Analysis of the cost structure of cognitive radio is on-going work in the Quasar project. We can compare MBBA using TV white space with MBBA deployment in the 800 MHz band. Although the uncertainty is high when estimating costs for cognitive radio equipment, some insights can be gained if we consider the overall cost structure for MBBA deployment. In figure 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 range 50 – 200 k€, in figure 4 will assume a cost of 100 k€ for deployment of a new site. The cost for upgrading existing sites with a fibre connection is estimated to 20k€ per site<sup>7</sup>.

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<sup>7</sup> [www.telenor.com/en/resources/images/cmd10-02-2-rolv-erik-spilling-modernisation-of-themobile-network\\_tcm28-56164.pdf](http://www.telenor.com/en/resources/images/cmd10-02-2-rolv-erik-spilling-modernisation-of-themobile-network_tcm28-56164.pdf)

The cost-capacity ratio of commercial radio equipment has improved more than 20 times the last few years. This is illustrated in figure 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.

From figure 4 we can draw one conclusion: even if the cost for cognitive radio equipment would be 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.

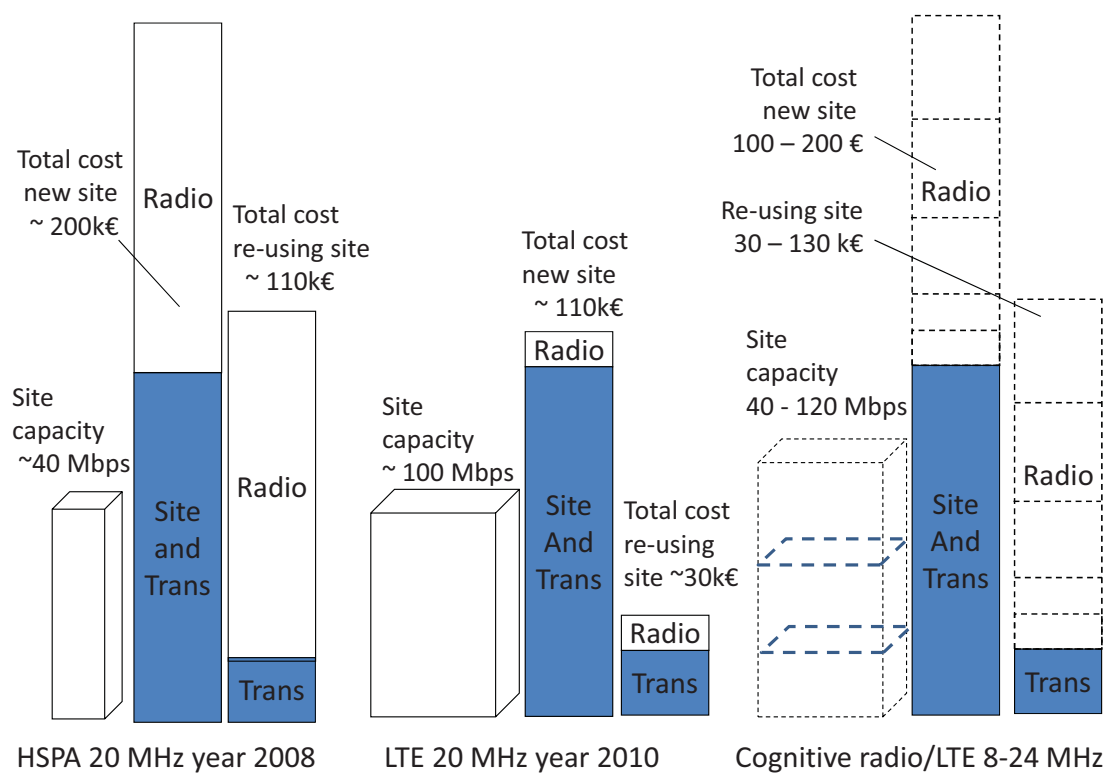


Figure 4 Example of cost structure for different types of radio access technologies. For the cognitive radio solution the indicated variation in capacity depends on the available bandwidth and the variation in costs for radio equipment depends on uncertainty.

For deployment of femtocells one challenge is the very large number of base stations that need to be deployed in order to provide the coverage. Even if each femtocell represents a low cost a very large number may make femtocell deployment less competitive than macrocell deployment (Markendahl and Mäkitalo, 2010). The network cost depends on the density of femtocells (Markendahl, 2011)

### ***Initial 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.

#### **Mobile broadband access in urban areas provided by a mobile operator**

In this business case 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 and that the cost for the cognitive radio is reasonably low then this business case has a good potential.

#### **Mobile broadband access in urban areas provided by a TVWSO**

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 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 5 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.

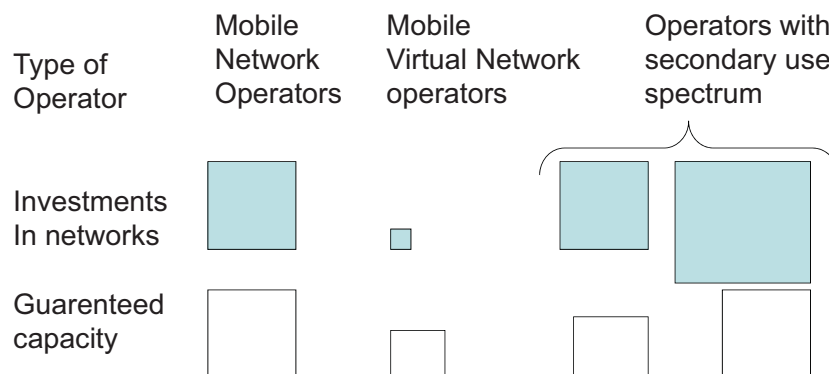


Figure 5 Comparison of investments and capacity for a mobile operator, a MVNO and a TVWSO

## **Mobile broadband access in rural areas provided by a TVWSO**

Also 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 we can see that the user demand expressed as Mbps per km<sup>2</sup> 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 2.

## **Indoor mobile broadband access provided by a local operator**

In this scenario a local indoor operator (e.g. a facility owner) 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. In order to provide wide area coverage or full coverage within large buildings a very large number of femtocell base stations are needed. For many scenarios femtocell deployment can be less competitive than macrocell deployment (Markendahl and Mäkitalo, 2010). The network cost depends on the density of femtocells (Markendahl, 2011).

However, in order to provide both coverage and capacity in hot spots and in offices femtocells are very competitive. In addition, the deployment of indoor system off-loads traffic from more costly macrocell networks and reduces or delays the need for investments in outdoor systems.

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

- i) That the band used for indoor access is separated from the bands that are used for macrocellular networks, this means no or less interference between macrocell and femtocell networks
- ii) That the frequency band used of the indoor access is not controlled by any mobile operator. Hence, it can be an unlicensed band (e.g. 1800 MHz) or a frequency band where secondary spectrum access is used. This means that the facility owner can act more independently and can offer the indoor access as a service closely linked to the facility and the indoor location.



## 6. Comments and implications

### *Implications for 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.

### *Interference problem with femtocells*

For mobile operators the joint deployment of femtocell and macrocell base stations results in interference and co-existence problems (Espino et al, 2010). One such problem is 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 is when employees can access femtocells at their home office but the visitors at the office are not allowed to. 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.

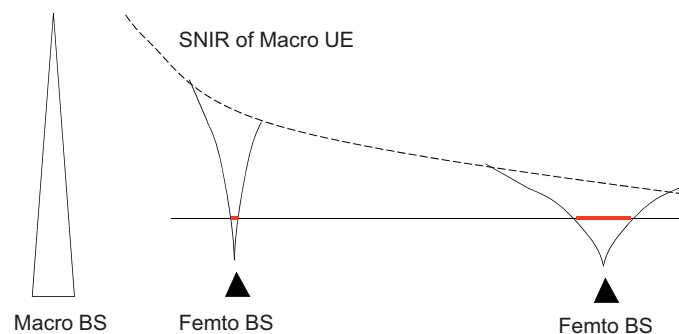


Figure 6 Illustration of dead zones appearing in the vicinity of femtocells. Due to the short distance to the femtocells the user equipment cannot connect to macro base stations

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 (Markendahl, 2011).

The advantage with a common and shared femtocell network using dedicated frequency bands (TV WS or unlicensed) would be that operators will avoid interference problems and at the same time can use all “own” spectrum for macro base stations (Espino et al, 2010).

### ***Capacity and bandwidth for indoor femtocells***

For indoor deployment using femtocells the need for high bandwidth needs to be analyzed 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 femtoells 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 offer s capacity corresponding to 100 users consuming 10 GB per month or 1000 users consuming 1 GB per month.

For femtocell deployment it would be feasible to reduce the bandwidth and still be able to serve a large number of users (Markendahl, Mäkitalo and Mölleryd, 2011). For indoor deployment one 8 MHz TV channel could then be split in 8 channels each 1 MHz.

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 (Markendahl & Mäkitalo, 2010).

## 7. Conclusions

We have analyzed a set of business cases where an 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.

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