MAPPING COGNITIVE RADIO SYSTEM SCENARIOS INTO THE TVWS CONTEXT

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ABSTRACT

Cognitive Radio has been one of the key research topics in the wireless community for about 10 years. The digital switch-over in the TV bands provides opportunities for Cognitive Radio Systems (CRS) to operate in the UHF spectrum under incumbent protection restrictions. Regulation bodies, in particular the FCC and OFCOM in the UK, have specified parameters under which CRS shall operate. In this paper we analyze key scenarios for CRS stemming from the QoSMOS project. Then, we analyze how these scenarios can be mapped into the TVWS context by considering link budget computation based on FCC and OFCOM transmit power recommendations as well as statistical propagation models for the UHF band. We also consider the expected capacity which can be achived when using TVWS as a capacity extension in an LTE network. We eventually conclude on the most promising scenarios in the context of the TVWS usage.

1. INTRODUCTION

Radio spectrum is a finite resource. There are many spectrum bands which already suffer from congestion, while at the same time there are other spectrum bands that are highly underutilized. Improved spectrum utilization is essential to allow for future wireless services to satisfy the increasing user demand for wireless capacity, coverage and quality of service. In an attempt to improve the utilization of currently underutilized spectrum bands, there is a growing regulatory trend to allow for license-exempt users to gain opportunistic access to spectrum that is in underutilized licensed spectrum bands. An opportunistic user must act as a cognitive radio in order to avoid interference with primary/licensed users. It should also cooperate fairly with other opportunistic users (also known as secondary/license-exempt/cognitive users).

"White space" (WS) is a term used to describe a part of radio spectrum (this will be described temporally and spatially as well as by its frequency) that can be available for opportunistic access. An issue that can occur with white spaces is the need for fairness among other opportunistic users which can make it difficult for commercial systems to provide high enough quality of service (QoS) guarantees when using white spaces alone. This is due to the fact that the load contributed by opportunistic users can be unpredictable, yet the provision of even a minimal service level will impose a lower limit on the available bandwidth required. In some scenarios systems may be able to function using white spaces alone, whereas other systems may use white spaces in addition to some licensed spectrum, to provide congestion relief and added functionality. In this paper white spaces existing in the TV band (TV white space (TVWS)) is considered as a particular band of interest as this band is currently being opened up for opportunistic channel access in many areas of the world.

Identifying scenarios at an early stage in system development is important as this can keep further development aligned, working with a common goal in mind. The scenarios identified in this paper are being used by the QoSMOS project [1], [2] to help guide the development of tools and techniques to bring these cognitive radio concepts closer to real-world systems. It can be noted that some of these scenarios are also considered by ETSI RRS [5]. The requirements for systems that could operate in these scenarios have been produced in [3] and [4]. However these scenarios can also offer guidance for cognitive radio developments outside of the QoSMOS project.

The structure of the paper is as follows. In Section II a description is given of the three scenarios and the criteria used to select them. In Section III we analyze how these scenarios can be applicable to the TVWS context bearing in mind regulatory constraints and statistical propagation models.

2. SCENARIOS FOR COGNITIVE RADIO SYSTEMS

If a Cognitive Radio System (CRS) is going to be attractive for most actors in the wireless industry, it has to provide a significant benefit compared to what is possible with today's and tomorrow's mainstream wireless technology. Mainstream technology like 3GPP's LTE, with the evolution towards LTE-Advanced, and Wi-Fi has a great momentum in the market, and will also provide significant improvements in performance as well as cost in the years to come.

2.1. Evaluation criteria

Three top criteria have been defined in order to select feasible deployment scenarios for a CRS providing both managed QoS and high mobility.

Benefit from CRS technology. The CRS solution should be able to provide a significantly better performance than existing (conventional) systems.

Benefit for actors. Deploying CRS for a particular scenario should provide a significant potential benefit for the actors. It should have a joint maximized benefit both for end users and industrial actors (This includes service providers and network operators, but could also include actors such as database administrators). A successful CRS should be commercially attractive. This criterion addresses the commercial side of the CRS, and the selected scenarios must be likely to provide a better business case than conventional systems.

Managed QoS and mobility. The scenario should cover a range of QoS and/or mobility demands. A scenario's QoS requirements depend on the traffic classes that it will serve and how demanding these traffic classes are.

Further, seven criteria have been used for targeting the most interesting and promising scenarios for business case studies.

Market Potential. The scenario should have a large market potential, e.g. with respect to the number of user terminals or expected revenue for the service. This potential could actually come from reduced costs, e.g. reduced spectrum costs or lower power requirements.

Best Solution. No other solution should appear as a better (w.r.t. e.g. performance, lower cost, have environmental benefits, etc.) solution for the given scenario.

Technical Feasibility. It must be probable that this system can be implemented with current state of the art technology or beyond state of the art technology achievable within a reasonable time frame.

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

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

Ecosystem Feasibility. The ecosystem may consist of customers, partners, suppliers, competitors and local and national authorities. If the scenario imposes great changes in the ecosystem (e.g. roles that disappear), it will be much harder to get acceptance for the solution in the industry.

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

2.2. Scenario descriptions and example use cases

Applying the criteria above has resulted in the scenarios described below.

2.2.1. Scenario "Cognitive femtocell"

The femtocell scenario, depicted in Figure 1, describes a user situation with low mobility, but high demands on throughput and QoS. It may also be described as a "hot spot" scenario. Femtocells are always connected to an infrastructure. Both indoor and outdoor deployment is possible.

The stakeholders in this scenario are both mobile and fixed operators as well as private and enterprise users. Examples of use cases for this scenario are:

- Private wireless access solution of the same type as Wi-Fi is used today.
- Public hot spots, where several femtocells comprise a larger coverage area.
- The use of indoor femtocells to provide outdoor coverage in e.g. urban/suburban streets.

The main benefits of using cognitive radio for femtocells are:

- Better interference control than current 3G/LTE femtocell technology which can improve capacity and coverage,

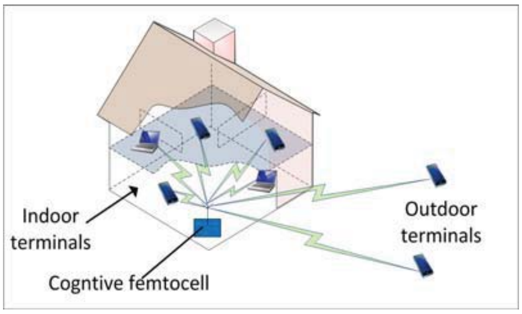

Figure 1. Overview of Cognitive Femtocell

- Better user experience due to more frequencies being available and potentially larger coverage.

2.2.2. Scenario "Cellular extension in whitespace"

Cellular extension in white space, depicted in Figure 2, is where mobile network operators (e.g. LTE-operators) will utilise white space spectrum in addition to their own licensed spectrum. The suitability of a spectrum band for this scenario depends on whether it is to be used for coverage or capacity enhancements.

The stakeholders in this scenario are mainly network operators and service providers. Examples of use cases for this scenario are:

- Increased mobile broadband coverage in rural areas with low traffic demand.
- Peak hour traffic offloading.
- Rural broadband involving the provision of wireless Internet connectivity to homes in rural locations through a base station.

The main benefits of using cognitive radio in this scenario are:

- Better user experience due to more frequencies being available and potentially larger coverage.
- Increased operational bandwidths, resulting in improved load balancing, improved link quality and more flexible services.
- The use of low frequencies increases range and the transmit power can be kept low. This reduces power consumption and reduces health risk concerns (especially for uplink transmissions).

2.2.3. Scenario "Cognitive ad hoc network"

The cognitive ad hoc network scenario, depicted in figure 3, typically includes properties of high dynamics and different nodes and terminals. Ad hoc networks are typically limited in space and time.

The stakeholders in such a scenario are, among others, end users (both private and enterprise), equipment vendors and the public sector.

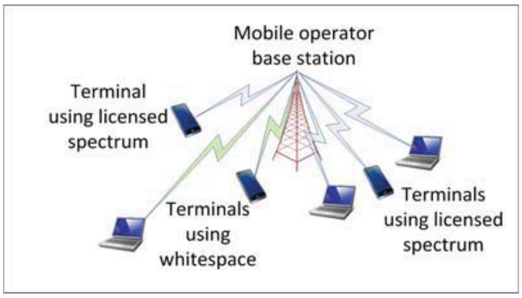

Figure 2. Overview of cellular extension in white spaces

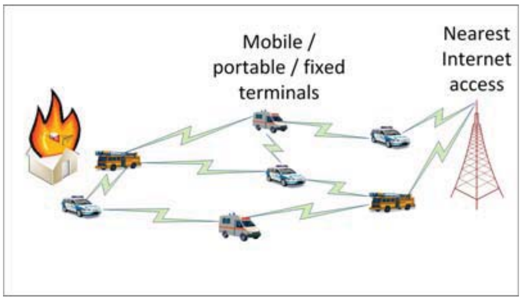

Figure 3 Overview of Cognitive ad hoc Network

Examples of use cases for this scenario are:

- Emergency ad hoc networks with several actors (police, paramedics and fire fighters) who will typically have two needs: One is to communicate efficiently between one another; the other is to establish a connection to a rescue co-ordination centre.
- A network established for a business meeting to exchange documents and other information. Dependent on the type of event, such a network may be partly pre-planned before the actual event.

The benefits of using cognitive radio for ad hoc networks are:

- The capacity can be increased to serve peak demands without the need for such bandwidth to be allocated during off-peak times.
- The use of low frequency bands is beneficial especially in emergency scenarios due the improved propagation through walls.

3. SCENARIO IMPLEMENTATION IN THE TVWS

3.1. Main parameters for TVWS usage

In this section we analyse how the scenarios described in section II applies to the specific case of the TV whitespace (470-790MHz band). To this aim, the allowed transmit power and the propagation conditions are key elements to determine the link budget for each scenario. In the following, we consider a "typical" transceiver with a 6 dB Noise Figure (NF) and a 1dB insertion loss. These values are derived from consumer UHF silicon TV tuner for which noise figure is between 4 dB and 10 dB. We also assume a SNR of 8 dB, which correspond to a capacity of 2.8 b/s/Hz using Shannon's capacity theorem. From these figures, maximum range can be computed based on statistical propagation models for each scenario.

The transmit power considered in this paper come from the FCC rules [6] and OFCOM statement [7]. The key parameters used hereafter are given in table 1. A channel bandwidth of 8 MHz is considered in the following calculation. Then, the budget for propagation loss can be computed for the transmit power values of table 1.

Table 1. Transmit power allowed by FCC and foreseen by OFCOM

Parameter	FCC	OFCOM
Power for FD in adjacent band	Not allowed	Not applicable
Power for FD in non-adjacent band with geo-location capability	30dBm (1W) (36dBm EIRP with 6dB gain antenna)	Not applicable
Power for PPD in adjacent band	16dBm (40mW) (Gain antenna not allowed)	4dBm
Power for PPD in non-adjacent band with geo-location capability	20dBm (100mW) (Gain antenna not allowed)	17dBm
Power for PPD in non-adjacent band without geo-location capability	17dBm (50mW)	

FD = Fixed Device ; PDD = Portable Personal Device

Table 2 Propagation budget

TX EIRP	36.00 dBm	20.00 dBm	17.00 dBm	4.00dBm
RX noise Power	-104.97 dBm			
RX Noise Figure	6 dB			
Required SNR	8 dB			
RX Antenna Gain	0 dBi (best case) or -7 dBi (worst case)			
Cable and Connector Loss	1 dB			
Building penetration loss	15 dB			
Minimum RX Levels:				
Best case	-94.97 dBm			
Worst case	-89.97 dBm			
Best case incl. build. pen.	-79.97 dBm			
Worst case incl. build. pen	-72.97 dBm			
Max Propagation Loss for Service:				
Best case	125.97 dB	109.97 dB	106.97 dB	93.97 dB
Worst case	118.97 dB	102.97 dB	99.97 dB	86.97 dB
Best case incl. build. pen.	110.97 dB	94.97 dB	91.95 dB	78.95 dB
Worst case incl. build. pen	103.97 dB	87.95 dB	84.95 dB	71.95 dB

The receiver (user terminal) antenna gain will vary according to terminal type and antenna solution. The typical gain is -7 dBi for a built-in antenna of a handheld terminal, which is the dimensioning case recommended by DVB-H [8]. The best case is not likely to exceed 0 dBi even for external antennas. Both cases are considered. In addition, we look at the use case of indoor-to-outdoor coverage for the cognitive femtocell scenario and model this by adding a penetration loss of 15 dB. The results for estimated maximum propagation loss for service are provided in table 2.

We intend to present average coverage figures, therefore the median path loss will always be calculated for the middle of the UHF TVWS frequency band (630 MHz) and no shadowing is accounted for. For a particular user a different carrier frequency and the presence of shadowing might significantly deteriorate or improve the link budget presented hereafter.

3.2. Range expectations for cognitive radio scenarios

Cognitive femtocell scenario, as well as the ad-hoc network scenario can be divided into two subcases. The first one corresponds to PPD to PPD communication. This link is expected to be a short to medium range indoor link in the femtocell case, with ranges similar to Wi-Fi. The second subcase is a wireless connection to the core network and corresponds to a FD to PPD case, where a long range communication is expected and where the PPD is expected to be fixed. This subcase also corresponds to a rural broadband access configuration. Because the PPD is assume to be fixed antenna gain at the receiver can be envisaged for the downlink. On the other hand, cellular extension in WS involves mobile PPD where no antenna gain at the receiver can be considered.

Thus, as far as range estimation is considered, the scenarios of section 2 can be classified into the categories of table 3.

Table 3. Mapping of QoSMOS usage scenarios to propagation scenarios

Usage scenario	Propagation scenario	Typical range
Cognitive femtocells and ad hoc	Indoor short range for PPD	1 – 100m
Cellular extension	Fixed long range access	1 – 10km
	Mobile cellular	0.1 – 10km

3.3. Range estimation for indoor PPD

These types of propagation conditions have been studied by Saleh and Valenzuela [9]. They propose to model the path loss by using the following equation:

$$PL(r) = 10\log_{10}\left(r^{-\alpha}\right) - 10\log_{10}\left(G_t G_r \left[\frac{\lambda_0}{4\pi}\right]^2\right) \quad (1)$$

Where r is the distance from transmitter, G_t, G_r are respectively transmit and receive gains of the antennas, λ_0 the wavelength of the signal in free space. α is the propagation path loss coefficient that varies from 1.5 to 6. The value of α is a function of the topology of the building where the propagation occurs. Typical values for UHF indoor propagations are between 3 and 4 for same floor propagation and 4 to 6 for propagation across multiple floors. These figures may notably be found in [10], where propagation models have been surveyed.

The distance for which quality of service is guaranteed can then be derived. We propose to use either an α of 3 or 6.

Table 4. Range for indoor PPD case

Carrier Frequency	630 MHz		
TX EIRP	20.00 dBm	17.00 dBm	4.00 dBm
Cell Range:	Best case (0 dBi Rx antenna)		
Indoor, α = 3	524 m	416 m	154 m
Indoor, α = 6	23 m	20 m	12.5 m
Indoor-to-outdoor, α = 3	166 m	132 m	48 m
Cell Range:	Worst case (-7 dBi antenna)		
Indoor, α = 3	306 m	243 m	90 m
Indoor, α = 6	17.5 m	15.6 m	9.5 m

Under these assumptions, the propagation under indoor conditions is thus expected to range from 10m to 500m depending on the building topology and materials. Therefore it can be concluded that indoor short range communication for portable devices is a viable scenario for TVWS operation. Indoor-to-outdoor communication is also viable, assuming that the indoor only path loss is kept low (α=3) with ranges from 50 to 170 m.

3.4. Range estimation for fixed long range access

In this scenario we suggest using the Okumara-Hata model of propagation. Path loss is given by the following equation for urban environment:

$$PL_{Urban}(d) = 69.55 + 26.16 \cdot \log(f) - 13.82 \cdot \log(h_b) - C_H + [44.9 - 6.55 \cdot \log(h_B)]\log d$$
$$C_H = 0.8 + (1.1 \cdot \log(f) - 0.7)h_m - 1.56\log(f)$$
(2)

where h_b is the height of the mobile antenna and h_B the height of the base station antenna. For sub-urban environment path loss is given by the following equation:

$$PL_{Suburban}(d) = PL_{Urban}(d) - 2\left(\log\left(\frac{f}{28}\right)\right)^2 - 5.4 \quad (3)$$

When considering broadband access, the receiver at the customer premises is located at a higher level (usually at the top of the roof), 4m is a reasonable average value. Secondly the receiver antenna may be highly directional, providing gains up to an extreme 20 to 24dBi. There is also an option to use a low-noise preamplifier to decrease the noise figure to 1…2 dB instead of 6 dB considered in the other scenarios. Therefore the maximum propagation loss may be typically equal to 146dB (using 20dB extra gain in the propagation path loss).

Table 5. Range for long range fixed access

Carrier Frequency	630 MHz
Mobile Terminal Height	4 m
Base Station Height	15 m
CH	5.59
TX EIRP	36.00 dBm
Max Propagation Loss	146 dB
Cell Range	
Okamura-Hata -- Urban	4.72 km
Okamura-Hata -- Suburban	8.27 km

This scenario gives relatively large propagation range up to almost 10 km, which validates the use of fixed access in the TVWS as far as a gain antenna at the receiver can be considered. It shall be noted though that in the femtocell case, the femtocell may be indoor and an additional loss for building penetration must be taken into account, reducing the range to slightly more than 2 km.

3.5. Range estimation for mobile cellular extension

This scenario corresponds to a cellular base station allowed to emit to power levels up to 36 dBm EIRP, and using the derivation from above, 119dB propagation loss budget. We also suggest for these channel conditions the use of the Okumara-Hata propagation model. The maximum expected coverage is then estimated and given in table 6.

Table 6. Range for mobile cellular extension

Carrier Frequency	630 MHz	
Mobile Terminal Height	1.5 m	
Base Station Height	15 m	
CH	0.00	
TX EIRP	36.00 dBm	
Rx antenna gain	-7 dBi	0 dBi
Max Propagation Loss	119 dB	126 dB
Cell Range		
Okamura-Hata -- Urban	0.63 km	0.97 km
Okamura-Hata -- Suburban	1.1 km	1.7 km

We are assuming a base station located 15 m above ground and antenna of the mobile terminal at 1.5m, and using the maximum allowed EIRP of 36dBm (or a maximum propagation path loss of 126 dB) as defined for fixed transmitters.

This gives maximum cell range of 600 – 1000 m for urban environments and 1.1 – 1.7 km for suburban environments. Therefore cellular extension in the TVWS can only be intended for rather small cells, like for instance in congested areas where TVWS can offload part of the cellular traffic.

For Non-Line-of-Sight (NLOS) conditions, which will likely be encountered for the mobile user scenario, the path loss model for the "Rural macrocell" scenario, defined by 3GPP in [12], can also be applied. The pass loss model defined in [12] is known to scale well down to 450 MHz, hence it is adequate to cover the TVWS. The mean path loss in dB has been found to be:

$$PL_{Urban}(d) = 161.04 - 7.1\log(W) + 7.5\log(h) - (24.37 - 3.7(h/h_B)^2)\log(h_B) + \\ + (43.42 - 3.1\log(h_B))(\log(d) - 3) + 20\log(f) - (3.2(\log(11.75h_{UT}))^2 - 4.97) \quad (4)$$

where W is the average street width, h is the average building height, h_B is the base station height and h_{UT} is the user terminal height.

The shadow fading is given as lognormal, with a standard deviation of σ = 8 dB for the NLOS case, σ = 4 dB for the LOS case within the so-called breakpoint distance, σ = 6 dB for the LOS case past the breakpoint distance.

These figures are in good agreement with the shadow fading data specified by TV broadcast recommendations and the mean path loss approximate the model of (2) and (3). For a mean propagation loss between 119 and 126 dB (worst and best case Rx antennas), the range is found to be between 600 and 900 m for the urban environment (W=20 m, h=10 m, h_B=15 m, h_{UT}=1.5 m).

4. CAPACITY CONSIDERATIONS FOR THE CELLULAR EXTENSION SCENARIO

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

4.1 Simulation model

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

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

i) A single LTE BS with one omnidirectional sector
ii) A single LTE BS with 3 sectors
iii) An "infinite" network of LTE BSs, each having 3 sectors.

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

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

In LTE UL, power control was applied to the active users so that the UE Tx power was adjusted with respect to the path loss to the BS it was connected to. A look up table was used to map throughput in terms of spectral efficiency (bps per Hz) with respect to calculated SNIR (= C/N+I) (dB) level. The tables were taken from the 3GPP TR36.942 document [14]. The maximum spectrum efficiency was 4.4 bit/s/Hz in downlink and 2 bit/s/Hz in uplink, giving maximum bitrates of 33.484 Mbit/s and 15.22 Mbit/s respectively.

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

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

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

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

4.2 Simulation results

Figure 4 shows the total bit rate as a function of the total site EIRP for indoor UEs.

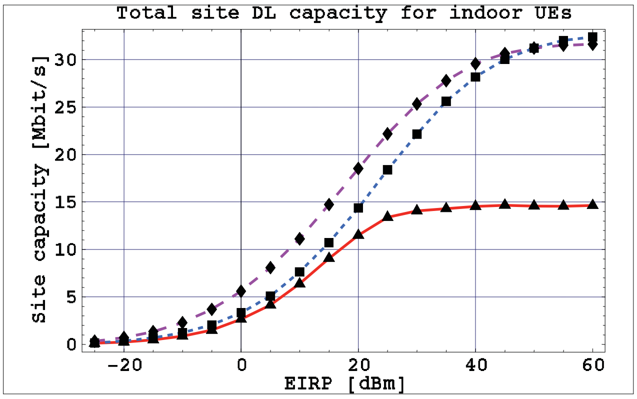

Figure 4. Total site capacity for indoor UEs for single cell with 1 sector (diamonds), single cell with 3 sectors (squares) and an "infinite" network of 3 sector cells (triangles). The Inter-site distance is 750 meters.

It can be seen that the internal interference in a multi-cell LTE network limits the site capacity to about 14.6 Mbit/s. The EIRP limits set by FCC for fixed devices (ref. table 1) are 36 dBm and 30 dBm, which corresponds to a site capacity of 14.3 Mbit/s and 14.1 Mbit/s respectively. Since this is only marginally lower than the maximum achievable capacity, it can be concluded that these EIRP limits will not limit the site capacity in this kind of network.

In the single cell (hot-spot) case the EIRP limits proposed by FCC and OFCOM will limit the capacity. For the single cell with 1 sector case, the maximum site capacity is 33.4 Mbit/s which is almost reached at an EIRP of 55 dBm. With a limit of 36 dBm for the sector EIRP, the site capacity will be reduced to 28.2 Mbit/s. The case of a single cell with 3 sectors has an even higher maximum site capacity, but a site EIRP of 36 dBm limits the site capacity to about 26.2 Mbit/s.

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

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

Figure 5 shows the uplink site capacity as a function of the maximum UE transmit power. The gain of the BS antenna was set to 6 dBi. All UEs was assumed to be located indoor.

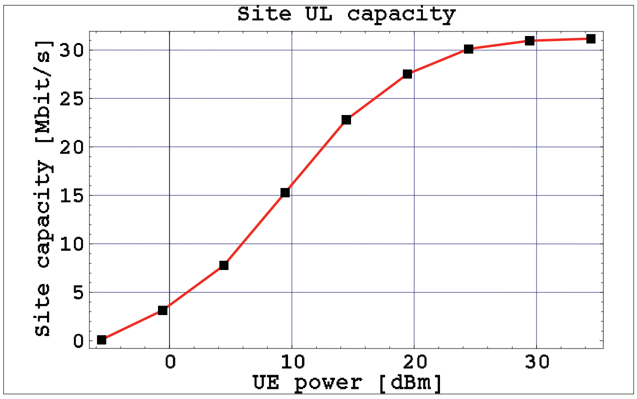

Figure 5. Total site uplink capacity as a function of the maximum transmitted UE power. All UEs are indoor.

According to Table 1, the maximum UE power when operating in a non-adjacent band is specified as 20 dBm by FCC and 17 dBm by OFCOM. This gives total site uplink capacities of 27.9 Mbit/s and 25.5 Mbit/s respectively, which is much higher than the achievable downlink capacities. For operation in adjacent bands, the maximum UE power is specified as 16 dBm and 4 dBm by FCC and OFCOM respectively. A maximum UE power of 16 dBm gives a site capacity of 24.5 Mbit/s, which also more than sufficient compared to the achievable downlink capacities. But a maximum UE power of 4 dBm, will give an uplink capacity of 7.3 Mbit/s, which is less than half the achievable downlink capacity. However, since many services require much lower uplink bitrates than downlink bitrates, even this uplink capacity should be sufficient in many realistic traffic scenarios.

5. CONCLUSIONS

Cognitive Radio concepts are applicable to many different scenarios. The TVWS secondary usage is the first opportunity where they could be deployed at a large scale. Regulation bodies are specifying the rules for white space operation in these bands, with an incumbent protection priority in mind. Therefore, transmit power is limited and this paper aimed at analyzing which of the scenarios can realistically be foreseen in the TVWS.

From the FCC and OFCOM figures link budget calculation and capacity estimates, it can be concluded that indoor WLAN-like scenarios and fixed broadband access are the most realistic scenarios among those considered by the QoSMOS project. Extension to cellular networks is also possible, but shall focus on dense areas where cells of 1 km are viable from a market point of view. This is typically the case where cellular system offload is required.

The additional capacity offered by cognitive radio in the cellular extension scenario will be limited by the EIRP limits in a single-cell case (hotspot), but still have an acceptable performance. In the multi-cell case, the capacity limitations are dominated by co-channel interference coming from neighbour cells.

6. ACKNOWLEDGMENTS

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