TVWS regulation and QoSMOS requirements

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***Abstract*—Regulatory regimes for opportunistic usage is being discussed in many countries for the so called TV White Space channels. The key objective of the regulators is to ensure that opportunistic systems can coexist with incumbent systems without causing harmful interference. However, they do not specify how these opportunistic systems must be designed to guarantee these requirements and to exploit White Spaces in an optimal way. This paper gathers key regulatory rules for opportunistic usage in the TV bands, and illustrates how these rules are turned into technical requirements within the framework of the European FP7 QoSMOS project.**

Keywords-TV White Spaces; regulation; requirements; opportunistic radio; QoSMOS

I. Introduction

Recently, there has been a growing interest in opportunistic radio, where secondary Opportunistic Radios (OR) can be operated over frequency bands allocated to some primary system in so far as this primary system is absent or, in a more general case, whenever harmful interference with incumbent systems is avoided. This hype was pushed by the many research activities on Cognitive Radio [1], but it was the recent discussions about the digital dividend in the TV bands by regulators that turned these activities into actual market opportunities. The FCC was the first to consider allowing licensed free operation in TV bands [2], provided incumbent systems protection can be guaranteed. At the same time, although not finalized yet, European regulators are considering how the digital dividend shall be utilized, with OR being one of the options under discussion. In most of these countries Digital Terrestrial Television (DTT) complete switch-over is planned in the 2011-13 period and the way the digital dividend shall be regulated has to comply with the same roadmap.

In Europe the EC has launched research projects on opportunistic radio for more than 5 years. The IST-ORACLE project [3] was the first one focusing on OR, although at that time actual deployment scenario was still to be set [4]. The aforementioned trend dictates that more concrete scenarios be defined and current research projects such as the ICT-QoSMOS [5] intend to consider regulatory regimes as strong drivers for the project's requirement. In this paper, the key currently discussed parameters considered by US and EU regulation bodies are discussed as a ground for setting the QoSMOS requirements.

This paper is organized as follows: section II briefly recaps how opportunistic systems have been considered by regulators and the two main operation strategies. Then, section III focuses on the regulation rules that have been agreed, or are being discussed, by regulators in the US and Europe. These requirements are then turned into technical requirements for the QoSMOS project in section IV.

II. Regulatory requirements aim and parameters

As far as opportunistic spectrum usage is discussed, regulators' main concern and aim is to ensure protection of incumbents from harmful interference. This implies that opportunistic radios need to adapt their transmission power to levels guaranteeing that this condition is met. Actually, two strategies can be envisioned to achieve opportunistic communication in this context. These are referred to as *underlay* and *overlay* communication.

In the undelay case, the opportunistic radio transmits in the same band as the incumbents, but at power levels low enough not to disturb the incumbents' receiver. In this case, the incumbents receive the opportunistic signal at levels similar or lower than the thermal noise. UWB is a technology where underlay strategy was applied. Indeed, spreading the energy over very large bands lowers Power Spectrum Density (PSD) and thus potential interference with incumbents. The drawback of this approach is that, this power spectrum density is so low that underlay can only be applied to very low power opportunistic usage, which directly translates into very short range communication. For instance the FCC requires a PSD as low as -41.3 dBm/MHz for below 10.5 GHz UWB transmission. Even under such constraints the FCC also requested the UWB devices to be able to detect the presence of WIMAX systems operating at 3.5 GHz and to switch off whenever such WIMAX transmission is detected. This eventually turns the underlay communication to operate in an overlay mode. Indeed, the overlay strategy entails allowing opportunistic transmission only when and where the incumbent signal is absent.

The aforementioned definition of the overlay approach translates into technical requirements for opportunistic system. Then, the fact that the opportunistic system needs to know where and when the incumbents are present leads to the following settings:

- *Before setting an opportunistic transmission*: detect any incumbent system presence in the area where secondary transmission is intended to operate. In fact the actual constraint is on guaranteeing that no victim device (i.e. incumbent receiver) uses the frequency targeted by the opportunistic system in the coverage area of this secondary system.

- When the opportunistic transmission is set: track the potential apparition of an incumbent signal and escape from the band whenever this situation occurs.

Then the requirements can be narrowed down into more technical terms as:

- Ability to detect incumbents. What is the required accuracy of detection?
- Ability to adapt transmitted power. What is the maximum power allowed?
- Ability to leave the band when incumbents switch on. What is the maximum time allowed for a secondary system to leave the band?

Regarding the first point, three options are considered by regulators. The first one relies on the fact that an OR is able to directly *sense* in order to detect the signal of the incumbents with a high sensitivity which is assumed to be far higher than any victim receiver's sensitivity. This means that the secondary sensor can detect the presence of the incumbent when it will be far out of the coverage zone of the incumbent system. Actually, the sensitivity requirements is set to put the secondary transceiver at a distance corresponding to the path loss of the incumbent, the pass loss of the opportunistic transmitter, and a certain margin also called 'no talk area' (Figure 1).

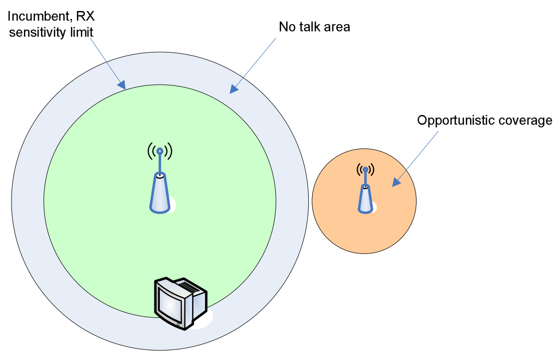

Figure 1. Simple view of incumbent protection concept

It can be easily understood that the higher the allowed power of the opportunistic transmission, the higher the constraint on the detector's sensitivity. On the other hand, lower transmit power translates into more potential opportunities.

The second approach to detect the presence of incumbents is through an indirect approach based on *geo-location*. With this strategy, the opportunistic radio determines its location and asks a database about the channel allowed for secondary usage at that place. Provided that the database, is updated in real time about the primary operation, it can answer the request by pointing to available channels and power levels allowed for each of them. It could even allow usage until some deadline is met. For the same reasons as stated in the sensing case, the location accuracy is traded against the allocated power for the opportunistic system.

Finally, the third option, known as *beaconing* relies on the transmission of a beacon that would indicate the presence of incumbents. This technique was never strongly considered by regulators though.

III. Regulatory Constraints in the TV White Space

Apart from the underlay regulation regime for UWB operation below 10.5 GHz, the TV bands is the only example where regulators have stronly considered the operation of opportunistic usage. This originated in most cases from the analog TV switch over towards full DTT services. Thanks to the better spectral efficiency of DTT over its analog counterpart, it is foreseen that part of the TV spectrum could be left to other applications among which opportunistic radio.

The FCC in the US was the first regulation body to enable unlicensed usage of TV bands. This was announced in Nov. 2008 [2] and the final rules were edited few months later [6]. In these rules, the FCC distinguishes two device profiles, either fixed or portable and sets power levels and detection capability accordingly:

- Fixed cognitive devices operate from a known, fixed location and can use a transmit power of up to 4 W. They are required to have a geo-location capability, capability to retrieve list of available channels from an authorized database, and a spectrum sensing capability. They can only operate on channels that are not adjacent to an incumbent TV signal in any channel between 2 and 51 with the exception of channels 3, 4, and 37.
- Personal/portable devices are restricted to channels 21 – 51 (except Channel 37) and are allowed a maximum transmit power of 100 mW on non-adjacent channels and 40 mW on adjacent channels and are further divided into 2 types: Mode I and Mode II. Mode I devices do not need geo-location capability or access to a database but must have sensing capability. Mode II devices, like fixed devices, must have geo-location, database access and sensing.

In these rules, the FCC sets signal sensing as the key means for incumbent detection. Sensing is a mandatory function that all the cognitive devices must implement. ATSC, NTSC and wireless microphone signals have to be detected at a level of -114 dBm. A channel must be sensed for 30 seconds before determining if it is available for use by a cognitive device. If a wireless microphone is not detected during this time and the database indicates that there is no TV signal present, then the channel is available for use. In the event that the sensing indicates the presence of a TV signal, but the database indicates otherwise, the sensing result must be communicated to the user who has the option of removing this channel from the available channels list. Once operation has started on a channel, sensing must be done at least once every 60 seconds and if a wireless microphone is detected the channel must be vacated within 2 seconds.

Geo-location means must be present in all fixed and Mode II devices, with an accuracy of +/- 50 m. This position information is used to query a database for a list of available channels that can be used for cognitive devices operation. The database will include information on all TV signals and may also have information on wireless microphone usage.

Because low power wireless microphones signal detection is challenging, dedicated channels for wireless microphone usage are defined in some major markets to be the first available channel on either side of channel 37. Cognitive devices cannot operate on these channels.

Very recently, on Sept.23rd 2010, the FCC has published a second Memorandum that allows TVWS communication for the specific application of so called “super WIFI hot spot”. For this application, spectrum sensing requirements are withdrawn and detection of incumbents is achieved through geo-location and database query. However, the FCC encourages continuous development of sensing capability because the FCC believes it holds promise to further improvements in spectrum efficiency in the TV spectrum in the future and will be a vital tool for providing opportunistic access to other spectrum bands.”

In the UK, the OFCOM started Digital Dividend Reviews since 2005, with the aim of analyzing the benefits of considering the use of interleaved spectrum by license-exempt applications. The last document in the series was issued in 2009 [8]. The guidelines suggest sensing based detection levels for sensing-only devices achieving a sensitivity of -114 dBm for digital TV and –126 dBm for wireless microphones. Accordingly to guarantee sufficient no-talk area, the maximum transmit power is allowed to be set at 20 dBm limited to 13 dBm on adjacent channels. Geo-location is also considered as an alternative with accuracy requirement set at 100 m. Recently, due to the difficulty of manufacturers to develop high sensitivity sensors at low cost, and in order to make this market emergence in a near future though, the OFCOM seems to go towards a geo-location only protection mechanism [9].

In Europe, the Electronic Communications Committee (ECC) of CEPT within the SE 43 group, which is tasked with defining the technical and operational requirements of operating in the TV white spaces with a first report, has delivered it in May 2010 and is already available on the CEPT webpage as a draft [10]. This work is based on studies of national regulators in Europe. [10] has analyzed a range of potential DTT receiver configuration which show that sensing requirements would range from -91dBm down to -165dBm. Because the latter figure cannot be achieved by current technology, it is expected that geo-location based detection shall be the way forward. Table I recaps the main requirements in the US and Europe.

TABLE I. SUMMARY OF REGULATION REQ. IN THE US AND EUROPE

	[6]	[7]	[8]	[9]	[10]
DTT detection sensitivity	-114dBm in 6MHz	Not required	-114dBm in 8MHz	Not required	Shall not be required
PMSE (wireless microphone) detection sensitivity	Same as for DTT	Not required	126dBm in 200kHz	Not required	Shall not be required
Geo-location accuracy	50m	50m	100m		Not specified yet
Transmit power (fixed) EIRP	4W	1W (with max 6dBi antenna gain)	100mW		Local specific
Transmit power (portable) EIRP	100mW	100mW	100mW		Local specific
Transmit power in adjacent bands to DTT signals	40mW	40mW	20mW		Local specific
Out of band radiation	-55dBm under the in-band level	-55dBm under the in-band level			
Time to vacate band after incumbent detection	2s				

IV. IMPACT ON QOSMOS

The QoSMOS system will be designed to function and operate in different environments. Six basic scenarios have been defined where QoSMOS is believed to be attractive and feasible. They encompass different ranges, mobility requirements, QoS requirements etc. Therefore, some of the requirements will be different dependent on the operating scenario. The different radio ranges for different scenarios are tabulated in table II.

TABLE II QoSMOS scenarios and typical ranges

Scenario	Range
Dynamic backhaul	10 km
LTE extension in WS	0.1 – 10 km
Rural Broadband	1 - 10 km
Cognitive Adhoc Network	1 – 100 m
Terminal to Terminal in Cellular	10 – 1000 m
Cognitive femtocell	1 – 100 m

In the QoSMOS project, we have identified four areas of requirements for a CR system. The list reflects the project’s view on what are essential features and functionalities of the QoSMOS cognitive radio (CR) system in order to be efficient technically as well as attractive from a business point of view.

- Business and user-related requirements address parameters and functions which shall ensure that the QoSMOS system will be attractive for actors and stakeholders. These are not directly related to the regulatory constraints, however the regulatory situation will influence to what extent the requirements can be met.

- Regulation and environment related requirements are a key category for any telecom system, not only wireless and not only cognitive, however it is important that future cognitive systems comply with emerging and changing regulatory regimes. These are the ones addressed in section II, and resulting requirements on co-existence are presented below.

- Performance related requirements are the classical technical parameters, mostly related to physical layer performance.
- Architecture and complexity related requirements address the network aspects of QoSMOS, and the two main goals are the need for reduced complexity and the necessary functional flexibility. Especially the need for interfaces is identified.

These categories of requirements are not independent of each other. Even if regulatory constraints are identified as a separate category they influence the other three to various degrees. Some of the consequential requirements are presented below.

A. Coexistence related requirements

One of the key factors of success for a CR system is that it is able to coexist with both incumbent systems and other opportunistic systems. The latter includes both systems of the same kind (e.g. different QoSMOS-deployments) and systems using different technologies.

Coexistence between systems: The overall QoSMOS system should be able to ensure coexistence between all sub-systems that could be potentially defined to address each specific scenario.

Interference avoidance: An opportunistic communication device operating in white spaces shall avoid interference to incumbent communications.

Coordination: A robust common logical channel for network coordination shall be available. This could be a dedicated common physical channel or a non-intrusive communication method, such as underlay spectrum sharing with very low transmit power.

B. Performance related requirements

The QoSMOS performance parameters that are considered important from the requirement point of view are spectrum utilization, data rates, latency, sensitivity, coverage and range and mobility. This performance related requirements are so chosen, that the QoSMOS cognitive radio system be viable not only in areas of spectrum shortages, but also be competitive to conventional systems where licensed spectrum is available.

Spectrum Utilization: The demand for increased throughput and data rates within given bandwidths demand more efficient use of the spectrum. In LTE and Mobile WiMAX, the spectrum efficiency requirements are approaching 4 bits/s/Hz in the downlink and the half in the uplink utilizing single antennas (SISO) by using up to 64 QAM modulations. A CR system should also be able to utilize the spectrum with high efficiency. Since spectrum access is more variable and dynamic it is of even higher importance that it is well used when available. In some scenarios (e.g. the cellular extension and cognitive femtocell) the spectrum efficiency should approach the current state-of-the-art, but in others this requirement may be more relaxed (e.g., ad hoc networks).

To meet FCC and OFCOM spectrum mask requirements, base stations and terminals must generate the radio frequency signal with high degree of precision. Technologies like IEEE 1588 time synchronization standard are used for this. Also, Network Time Protocol (NTP) is being pursued by some developers as a possible solution to provide frequency stability. Conventional (macro cell) base stations often use GPS timing for synchronization and this could be used, although there are concerns on cost and the difficulty of ensuring good GPS coverage.

Out-of-band Radiation: To meet the regulatory requirements, low out-of-band leakage is extremely important for the QoSMOS opportunistic system. The signal generation should have steep spectral roll-off to ensure the best spectral occupation, otherwise frequency guard intervals will be needed impacting the spectral efficiency dramatically. For instance, using traditional Orthogonal Frequency Division Multiplex (OFDM) multi carrier system would generate very high side lobes at around -13 dB; which would definitely interfere with the incumbent channels. Another approach under consideration is Filter Bank Multi Carrier (FBMC) technique, which has shown the secondary power side lobe to be at around -40 dB.

Data Rates: The QoSMOS cognitive radio will take into consideration some very different and varied use cases. These indoor/outdoor, short/long range use cases have different demands for data rates. To be able to cater to all these varied requirements, the QoSMOS transceiver need to satisfy the most stringent demands for high data rates. In the cellular network scenario for instance, the LTE specification provides downlink peak rates of at least 100 Mb/s, an uplink of at least 50 Mb/s and RAN round-trip times of less than 10 ms. Peak download rates of 326.4 Mb/s for 4x4 antennas, and 172.8 Mb/s for 2x2 antennas (utilizing 20 MHz of spectrum). Peak upload-rates are 86.4 Mb/s for every 20 MHz of spectrum using a single antenna. Hence, the QoSMOS system should be able to provide comparable peak data rates to the LTE system provided equal assumptions on spectrum available and antenna configuration are valid.

Latency: Achieving seamless inter-operability with the existing network components is essential to improve consumer experience. Once the inter-operability is achieved, providing the end-to-end QoS is a challenge due to the inherent characteristics of such public IP network. The packet delay variation can lead to significant jitter or packet reordering issues, thereby impacting the QoS of conversational and streaming traffic classes while an overall delay in packet transmission will severely impact the end-to-end latency for voice and video services.

Mobility: Mobility is an important parameter in QoSMOS and the system should ensure respectable QoS even in mobile scenarios. It should be noted though, that the most stringent QoS scenario is the wireless backhauling one, which does not involve mobility. Fast handovers need to be implemented to ensure seamless transfer of service from one station to another. In addition, the physical layer needs to handle the varying radio channel w.r.t. fading and multipath transmission. Mobile scenarios of more than 100 km/h are not envisaged for certain use cases, and even lower mobility is expected for femtocell environments. For dynamic backhaul, mobility is even more limited. Fast mobility and achievable throughput are contradictory requirements and must be seen combined. A high throughput cannot be combined with high mobility and vice versa.

Coverage and Range: Different scenarios and use cases will represent different coverage and ranges. The QoSMOS system should handle all of them. This means that it should be possible to operate QoSMOS on small scales with very low transmit power up to higher power stations providing long ranges. An efficient power control will minimize the interference level and make it possible to adapt quickly to changes in the environment. Table II shows the radio ranges of different scenarios that are being considered in the QoSMOS system.

Hence, the QoSMOS system should be able to provide coverage from very small ranges like femtocell with a few meters to long range cellular extensions and rural broadband. It should include a dynamic coverage control to handle quick changes in the radio environment.

C. Architecture and complexity related requirements

The QoSMOS system will be adaptable to different network topologies which together with the regulatory constraints puts requirements on the architecture.

Interfaces with external systems: Several QoSMOS systems could exist in the same area. To ensure efficient operation for all, a collaborative approach should be possible. The collaboration could be materialized by an interface between the QoSMOS sub-systems. In the QoSMOS architecture, an adaptation layer abstracts the communication plane to the cognitive plane enabling heterogeneous RATs support.

Information collection: As an important co-existence mechanism identified by some regulators, the white space database is considered in the process of defining the QoSMOS architecture. Especially, an interface between some of the QoSMOS architecture building blocks and a white space database shall exist as well as the appropriate interfaces between the architecture building blocks to ensure the spreading of the white space database data across the architecture. The QoSMOS portfolio can be viewed as an enhanced version of the database provided/required by regulators. The additional features may improve the performance, while obeying regulator database rules. In addition to white space database information, the QoSMOS system may be constrained by other regulation rules and policies. As such there shall be interfaces allowing the QoSMOS system to get these rules and policies from an external entity. Sensing technology is foreseen as an efficient means to populate the portfolio to improve White Space operation efficiency (interoperability, coexistence, QoS, handovers).

Response time: Among the regulation requirements, there is one defining the maximal time for a secondary system to vacate a channel when a primary user appears in the secondary system operating channel. The system response time has to be compliant with the regulation rules. The system response time is defined as the time between the detection of the primary user and the enforcement of the reconfiguration decision (the reconfiguration decision can consist in stopping the transmission, moving to another band…). The architecture shall consider this requirement when defining the distribution of the decision making across the system and when defining the protocols (especially regarding the protocol layer: higher layer protocols have a lower response time compared to low layer protocols).

V. CONCLUSION

This paper focussed on the QoSMOS project requirements considering the regulatory rules as a starting point. Additionally, the paper has shown that the requirements are influenced by other factors, such as the usage and deployment conditions. The variety of scenarios considered makes the project believe that there will not necessarily have one unique radio technology fulfilling all of them, but rather than a collection of radios are likely to emerge in the white spaces. For that reason, QoSMOS has been developing an architecture capable of handling several radio technologies in a single framework, and the data archive mechanisms enabling enhanced coexistence and QoS for these systems.

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