Quality Of Service and MObility driven cognitive radio Systems

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QoSMOS

D1.4

QoSMOS consolidated system requirements

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Editor(s):	Per H. Lehne (TEL)
Author(s):	Ulrico Celentano (UOULU), Janne Lehtomäki (UOULU), Dominique Noguet (CEA), Rohit Datta (TUD), Philippe Delahaye (NTUK), Rainer Wansch (Fraunhofer), Vincent Berg (CEA), Pål Grønsund (TEL)
Reviewers:	Genevieve Mange (ALD), Jonathan Duplicy (Agilent), Atilio Gameiro (IT), Mario Schühler (Fraunhofer)
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Abstract:

This report specifies the system requirements for the QoSMOS project. The list of requirements 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. Requirements are defined in four major categories: Business, Service and User; System Operation; Performance; and Architecture and Complexity. Under these categories, a number of requirements are given together with their corresponding rationales. The requirements impact on the technical work is described as well as the constraints imposed by the QoSMOS scenarios.

Keyword list:

Cognitive Radio, Requirements, Performance, Business value, Complexity, Regulations

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Abbreviations

3GPP	3rd Generation Partnership Project
ARNS	Aeronautical Radionavigation Service
ATSC	Advanced Television System Committee
BS	Broadcasting service
CAPEX	Capital Expenditures
CEPT	The European Conference of Postal and Telecommunications Administrations (Conférence Européenne des Post et Telecommunications)
CR	Cognitive Radio
DD	Digital Dividend
DFS	Dynamic Frequency Selection
DME	Distance Measuring Equipment
DoS	Denial of Service
DSA	Dynamic Spectrum Access
DTT	Digital Terrestrial Television
EIRP	Effective Isotropic Radiated Power
ECC	Electronic Communications Committee
FCC	Federal Communications Commission
HSPA	High Speed Packet Access
IEEE	The Institute of Electrical and Electronics Engineers
ISM	Industrial, Scientific and Medicine, name used for the spectrum commons in the 2.4 GHz band
LTE	Long Term Evolution
NTSC	National Television System Committee
OFDM	Orthogonal Frequency Division Multiplex
OPEX	Operational OPerational EXpenditures
PMSE	Program Making and Special Event
PSD	Power Spectral Density
QoS	Quality of Service
RAS	Radio Astronomy Service
RAT	Radio Access Technology
RRM	Radio Resource Management
SNR	Signal-to-Noise Ratio

T2T	Terminal-to-Terminal
TCO	Total Cost of Ownership
TPC	Transmit Power Control
TVWS	TV White Space
UHF	Ultra-High Frequency, band designation for 300 – 3000 MHz
UMTS	Universal Mobile Telecommunications System
UWB	Ultra Wide Band
Wi-Fi	Trademark for the Wi-Fi Alliance
WiMAX	Worldwide interoperability for Microwave Access

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1 Executive Summary

This report contains a set of requirements that are believed essential for the QoSMOS system to become attractive. Cognitive radio (CR) is in its early stages, and has yet to prove its viability, both from a technical and business performance point of view.

The main pillars for the QoSMOS system are Quality of Service (QoS) and mobility support while exploiting opportunistic spectrum access. Therefore, this is reflected in almost all requirements.

Another important property of QoSMOS is the flexibility with respect to operating frequency. This means that the QoSMOS system as a whole shall be able to operate at any frequency band which is made available for opportunistic access. However, the realization and deployment of QoSMOS will be limited to available frequency bands, dependent on the local or regional regulatory situation. Currently identified bands are limited to the so-called TV Whitespace in the UHF band from 470-790 MHz, but other bands are identified and discussed.

It is expected that more frequency bands will be available for opportunistic or dynamic frequency access in the future, like e.g. bands which today are exclusive to military use.

The requirements for QoSMOS are sorted in four main categories. In each category a top-level requirement is defined from which the more specific requirements are derived.

Business, service and user-related requirements:

> "*The QoSMOS system should be competitive to other technologies and show a proven benefit in relevant markets and scenarios.*" (Competitiveness of the QoSMOS system)

Requirements in this category address parameters and functions that shall ensure that the QoSMOS system will be attractive for business actors and stakeholders. QoSMOS must substantiate the viability for business of the system. The most important side of this is to ensure that the system is designed to be cost-effective in all phases: development, production, operation, use, disassembly and recycling. Such requirements are not easy to quantify, but a CR system will be compared to conventional technology in the business community and among users. Main requirements here are on the economy of the system, services towards end users and service providers and support for different terminal types.

System operation related requirements:

> "*The QoSMOS system shall be flexible and adaptable to differences in regulations given for the regions and markets in which it is intended to be deployed.*" (Regulatory compliance)

It is important that future cognitive systems comply with emerging and changing regulatory regimes. QoSMOS must comply with the constant change in global, regional and national regulations related to opportunistic spectrum access. Hence QoSMOS must be able to adapt to various regulatory requirements. It comprises requirements mostly related to how QoSMOS should behave operationally. Main requirements in this category are on regulatory constraints on areas like sensing ability, power limitations and geolocation accuracies.

Performance related requirements:

> "*The QoSMOS system's technical performance should be good enough to meet users' expectations of the service delivered.*" (Technical performance)

These are the classical technical parameters. The performance of the QoSMOS system must be comparable to conventional systems, but this is not a pure technical issue. Technical performance may e.g. be traded-off for e.g. price. The important is to meet user's expectations. That is also the reason why direct QoS-requirements are included here. The latest developments in wireless system performance from 3GPP and IEEE have been used to determine reasonable requirements. Cognitive radio should not only be viable in areas of spectrum shortage, but also be competitive to conventional systems where there is licensed spectrum is available. These are prerequisites for comparing business cases. Main requirements here are on QoS, mobility and physical layer and access network performance.

Architecture and complexity related requirements:

> "*The QoSMOS architecture shall ensure complying with other external systems and ensure flexibility and scalability*." (Architecture and complexity)

These address the network aspects of QoSMOS, and two goals have been addressed: the need for reduced complexity and the necessary functional flexibility. The architecture and complexity are closely related. It is important that the QoSMOS system is as simple and modular as possible, both for supporting a low cost deployment, but also ensuring flexibility and scalability. This category comprises requirements on interfaces to ensure co-existence, interworking and heterogeneity with other QoSMOS systems and other radio access technologies, as well as security, flexibility and scalability.

Deploying QoSMOS in different scenarios puts different constraints on the system. The QoSMOS scenarios vary from short range to long range, indoor and outdoor, low to high mobility. The most apparent differences in deploying QoSMOS in the different scenarios deals with the choice of frequency, grade of mobility, QoS, bandwidth needs, transmitter power range, and interference handling.

2 Introduction

This report specifies system requirements for the QoSMOS project. They have been conceiver through an iterative process between WP1 and the other WPs. The list of requirements reflects the project's view on what are essential features and functionalities of the QoSMOS cognitive radio system in order to be efficient technically as well as attractive from a business point of view.

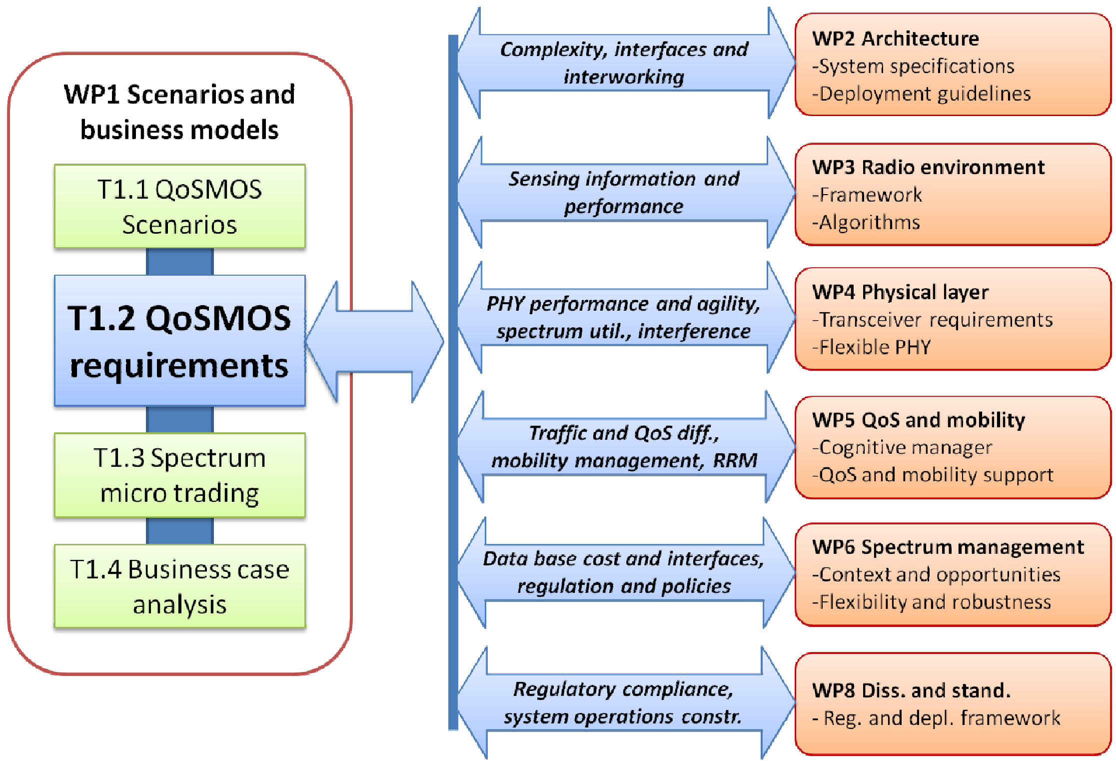

Figure 2-1 Process and interaction between WP1 and the other WPs in defining the QoSMOS requirements.

Scope

The scope of this document is the specification of requirements for the QoSMOS system, so that it will be able to comply with its goals. The definition of exact numerical values has been on purpose kept out of the scope since this step will be pursued in the technical work. The requirements in this report are defined to be used for the research, specification and design of the QoSMOS system. This will ensure that the QoSMOS system will not only comply with its constraints, both external (e.g., regulations,) and internal (such as quality of service), but it will also embed solutions that are technologically feasible.

QoS and mobility

The QoSMOS project's main objective is to "research and develop the tools and techniques that allow opportunistic use of radio spectrum where users are moving, while receiving a managed Quality of Service (QoS)". QoS and mobility are consequently two main pillars of QoSMOS and they influence almost all aspects of the QoSMOS design. Requirements addressing QoS and mobility are described and included in the complete set.

QoSMOS scenarios

The QoSMOS system will be designed to function and operate in different environments. In QoSMOS D1.2 [1] six basic scenarios have been defined where QoSMOS is believed to be attractive and feasible. They encompass different radio ranges, mobility requirements, QoS requirements, etc. The requirements are generally not uniform for the system. Where applicable, a discussion on the different requirements related to the consolidated scenarios is included. There are no solutions prescribed in this report, since this is part of the system specification work to be done in WP2 (D2.3).

The radio ranges for different scenarios [1] are tabulated in Table 2-1. The numbers are indicative and show the order of magnitude (for example, 10 km means ‘tens’ of kilometres, thus including, e.g. 60 km as a feasible value). They do not imply strict boundaries.

Table 2-1 QoSMOS scenarios and typical ranges

Scenario	Range
Dynamic backhaul	10 km
Cellular extension in White Space	0.1 – 10 km
Rural Broadband	1 – 10 km
Cognitive ad hoc Network	1 – 1000 m
Direct Terminal-to-Terminal in Cellular	10 – 1000 m
Cognitive femtocell	1 – 100 m

Report organization

The report is organized as follows:

We start with chapter 3 with a description of the methodology and terminology used in this report. In chapter 4, we discuss how QoSMOS should be able to handle different frequency bands, and identifies the options in the short, medium and long term.

In chapter 5, Business, service and user related requirements are described. This comprises economy-related requirements, service-related requirements and terminal-related requirements. Economy is dealing with aspects like system costs for different actors and stakeholders, while Services are basically related to end user QoS and the ability to manage and differentiate between traffic classes and mobility handling. The terminal-related requirements are in this report restricted to the end-user viewpoint addressing different terminal types and capabilities.

Chapter 6 presents requirements related to System operations. The regulatory picture is in constant change and therefore a more comprehensive description of the background is given in Appendix. Current requirements are extracted from FCC and Ofcom’s latest rulings (2009 [3] [4] and 2010) [5] and from draft requirements produced by CEPT ECC (SE43) [6] related to parameters like transmitter power and evacuation times.

In chapter 7, performance related requirements are given. These include essential requirements on QoS and mobility, but also basic technical requirements like throughput, spectrum efficiency, latency and coverage.

In chapter 8, the architecture and complexity is addressed. These include requirements to supporting interworking and co-existence with other radio access technologies (RATs), including the necessary interfaces and architecture functions. Flexibility, scalability and security are also addressed.

Finally, in chapter 9, the scenarios' influence on the interpretation of the requirements is summarized in table format and chapter 10 contains the conclusions.

Three appendices are added to the report: Appendix A is a table summary of all requirements showing their inter-relations. Appendix B gives background on the approach for incumbent detection by sensing, while Appendix C gives background on the approach to emission limits in the 470-790 MHz band.

3 Methodology and terminology

This chapter explains the methodology used for presenting and organizing the requirements in the document.

The requirements for the QoSMOS system must reflect the actual situation and be precise and have a targeted scope. Requirements shall be able to handle:

- That QoSMOS shall be flexible with respect to operating frequencies
- That different scenarios imply different specific requirements on the system
- That different regions and countries probably will impose different regulatory rules, also related to the same frequency bands.

The three points above are not mutually independent. The requirements have been defined to be universally applicable to the above demands, however some of them can only be interpreted by in the light of identified frequency bands and operating scenarios.

A two level hierarchical approach has been selected. For each category, one high level requirements are defined which shall grasp the essence of all requirements within the category. On the level below, there are more specific requirements which are derived from the high level requirements.

Each requirement is identified by a letter code which makes cross-referencing easy. The overall structure is shown in Figure 3-1, and the top level letter code used is defined in Table 3-1.

Figure 3-1 QoSMOS requirements, overall structure

Table 3-1 QoSMOS designated letter codes for categories (top-level)

Code	Category
B	Business, service and user related requirements
S	System operation related requirements
P	Performance related requirements
A	Architecture and complexity related requirements

In the following chapters, each requirement is presented in a table format containing the following issues:

- **Req. ID**: the letter code as defined above
- **Title:** The issue covered by this requirement
- **The requirement text**, usually in the form "The QoSMOS system shall/should…" etc.
- **Related requirements,** listed by their Req. ID. This is also summarized in tables in Appendix A
- **Related QoSMOS WPs:** How this requirement is related to the work in the different QoSMOS workpackages:
    - **WP1:** Scenarios and business models

  - **WP2:** System architecture
  - **WP3:** Radio environment mapping and sensing
  - **WP4:** Physical layer architecture
  - **WP5:** Mobility and QoS
  - **WP6:** Cognitive spectrum manager
  - **WP7:** QoSMOS proof-of-concept
- **Scenario constraints:** A discussion on how this requirement is affected by deploying QoSMOS in the six defined scenarios (see Table 2-1)
- **Notes**: Any remarks which helps in clarifying and interpreting the requirement

Definitions

In this report we refer to QoSMOS in three ways, dependent on the scope:

- The QoSMOS *system* is the complete set of functions and modules which is being specified and designed in the project. An example is the complete reference architecture defined in D2.2. [2].
- A QoSMOS *realization* is an implementation of those functions and modules of the complete QoSMOS system which is necessary to fulfil the requirements (functional, regulatory, performance) of operation under the constraints of a certain scenario and region.
- A QoSMOS *deployment* is the delivery, installation, and testing of the QoSMOS realization in order to put it in operational state.

In this report, we also have the following understanding related to co-existence and spectrum sharing models:

- *Co-existence* is applied to both other QoSMOS deployments and other opportunistic users or systems.
- *Underlay operation* means that the opportunistic radio transmission occurs within the coverage of an incumbent transmitter and in the same band and at the same time as the incumbents, but at a power level low enough to avoid disturbances of the incumbents' receivers.
- *Interweave operation* is based on interference avoidance and means dynamic exploitation of spatial and temporal spectral opportunities in a non-interfering manner. This translates into exploiting unused resources, so-called whitespaces in the frequency band in an opportunistic manner.
- *Overlay operation* means that the opportunistic user just causes no interference to incumbent communication, or it even relays the known incumbent message together with its own message, respectively using coding methods.

The above three spectrum sharing models are more comprehensively described in QoSMOS deliverable D6.1 [12].

4 QoSMOS frequency flexibility

The QoSMOS system is supposed to be flexible with respect to operating frequency bands. This does not imply that frequency is irrelevant for QoSMOS. A given realization of QoSMOS will for sure be *frequency-specific* or *frequency-dependent* and it must follow the corresponding regulations. This is taken care of by defining the requirements in a frequency-agnostic manner, and the interpretation and corresponding quantification must be done in light of operating frequency band and regulations.

The QoSMOS system design will consist of both frequency independent and frequency dependent parts, which also is reflected in the organization of the QoSMOS project. The QoSMOS system itself is frequency independent by definition but the design of the QoSMOS system will take into consideration also frequency-dependent aspects that will be then part of a QoSMOS realization. In general it is possible to say that the closer one is to the physical layer, the more frequency dependent the design will be. Typical frequency independent parts of the QoSMOS system are:

- The system architecture (WP2)
- The spectrum management framework (WP6)

The QoS and mobility solutions (WP5) will contains issues both of frequency independence and dependence.

Some of the solutions developed in the above workpackages may be realization-dependent (e.g., as enhancement of a legacy standard) but not frequency-dependent (if operating frequency is transparent for the specific solution). The clearly frequency dependent parts of the QoSMOS system are:

- The radio environment mapping and sensing (WP3)
- The physical layer architecture (WP4)

Regulation of frequency bands for opportunistic use is in its infancy and we have identified bands which are available now, and bands which may be possible to use in the future.

4.1 Currently identified frequency bands

Table 4-1 lists one currently identified frequency band. When more bands are becoming available for use by systems like QoSMOS, these may be added to the list.

Table 4-1 Identified frequency bands for opportunistic access

Band #	Frequency range	Description	Regulatory situation
A	470 – 790 MHz	The so-called TV Whitespace (TVWS) band,	**Europe:** Consultation conducted by Ofcom (UK) [4]. Technical requirements are produced by CEPT [6]. **US**: currently made available for opportunistic spectrum access in the US under given conditions [3].

4.2 Prospective frequency bands

Prospective bands for QoSMOS are being studied in the project, however it is too early to state whether they will be open for opportunistic spectrum access in the future. These are listed in Table 4-2.

Table 4-2 Prospective frequency bands for opportunistic access

Band #	Frequency range	Description	Regulatory situations
B	790 – 862 MHz	Often called the "digital dividend" (DD). The upper part of the TV band (channels 61-69)	In many European markets this band is being auctioned by the regulators for mobile broadband
C	2.4 – 2.5 GHz	The ISM (Industrial, Scientific and Medical) band, a license exempt band used for Wi-Fi, Bluetooth, ZigBee and other short range technologies	Spectrum commons in the US and Europe. Use based on maximum power spectral density and EIRP limitations.

4.3 Future candidate frequency bands

Since the QoSMOS system is designed to be frequency agnostic, it opens up the possibility of supporting virtually any frequency band made available for opportunistic access.

It is expected that more frequency bands will be available for opportunistic or dynamic frequency access in the future. Some regulators have already signalled that e.g. frequencies which today are exclusive to military use may be opened for shared use employing dynamic spectrum access (DSA) or even opportunistic spectrum access (OSA) [**Error! Reference source not found.**].

The Swedish Post and Telecom Agency (PTS) published on December 7 2010 a decision to reduce the amount of frequency space for the Swedish Armed Forces by just over 6 000 MHz compared with previously [7]. According to the press release, PTS and the Swedish Armed Forces have come to an agreement regarding the bands to be shared by civilian and militaries. For instance, civilian mobile video links now have almost 140 MHz more frequency space through this agreement. The conditions for this kind of sharing will be produced by the PTS when equipment with DSA technology is available on the market. It is also the first time a PTS decision contains a general condition providing that PTS can allow other use in military bands with DSA. Further details are not known, since the decision has been classified.

The ICT QUASAR-project has defined possible scenarios for opportunistic use in different frequency bands [8]. This includes the TV Whitespace as defined above, but also others:

- Radar bands from 2.7 – 2.9 GHz, 2.9 – 3.1 GHz and 5.25 – 5.85 GHz are possible candidates. The 5 GHz-band is currently used for Wi-Fi (802.11a) where a number of algorithms to protect radar is used (dynamic frequency selection – DFS, transmit power control – TPC, etc)
- The aeronautical band 960 – 1215 MHz is used for DME (distance measurement equipment), and is proposed for indoor use.

The use of QoSMOS technology in planned bands, e.g. the IMT-band 2.5 – 2.7 GHz (3GPP band 7) is also an interesting prospect which is studied from the sensing point of view in WP3.

5 Business, service and user related requirements

QoSMOS must prove that it is viable in the market place, The QoSMOS system will be compared to conventional technology, like e.g. the 3GPP-family (UMTS/HSPA and LTE) and IEEE technology (WiMAX and Wi-Fi) in the business community and among users.

The top-level requirement in this category reflects the need for competitiveness and that the QoSMOS system's success in the end is dependent on the market adoption.

Req. ID:	**B.top**
Title:	Competitiveness of the QoSMOS system
Text: *The QoSMOS system should be competitive to other technologies and show a proven benefit in relevant markets and scenarios.*	
Related requirements:	Relevant for all work in QoSMOS
Related QoSMOS WPs:	Relevant for all work in QoSMOS
Scenario constraints:	The competitiveness in the different scenarios defined in QoSMOS deliverable D1.2 [1] will most likely be different in different markets and under different regulatory constraints.

5.1 System economy

One of the main ideas behind QoSMOS is to challenge the current value chain for mobile broadband, by lowering the barriers to market entry for service providers. However, this should also include the opportunity for existing cellular network operators and service providers to lower their costs, increase revenues and provide a better service. All actors and stakeholders must see an economic related benefit in order for QoSMOS to be a success. Currently the following actors (participants of the ecosystem) and stakeholders (parties which may have financial or societal interests) have been identified.

- Regulators
- Equipment vendors
- Spectrum data base owners
- Existing cellular operators
- Existing fixed line/broadband operators (without cellular operation)
- Application providers
- Service providers
- End users
- Public authorities

This list of actors and stakeholders will be addressed in depth and revised in Task 1.4 of the QoSMOS project (Business and deployment models analysis and evaluation).

The cost of a system is divided into two main categories, the investment cost (Capital Expenditure – CAPEX) and the operational cost (Operational Expenditure – OPEX). Energy consumption is one factor which probably should have increased attention. Also long term expenses like replacements, upgrades and upscaling and decommissioning could be part of the picture. In total this is often referred to as "Total Cost of Ownership" – TCO. The total cost in the value chain comprises the costs for the different actors. A value chain for a cognitive radio system will not be the same as for e.g. a licence based cellular system. First, the actors and stakeholders may not be the same and, second, the balance between them may be different. However there will be some actors who may face a choice of engaging in mainstream technology or in cognitive radio technology. Most likely, large actors in the wireless industry will engage in both. The other side of business is the top-line of the economy. To some extent, a similar or even higher cost picture could be viable if the prospects for increased revenues are promising enough. The latter can be that new applications are made possible (increased revenues). Another example is spectrum sharing among telecom operators which can increase revenues and reduce costs. This requirement is addressing the cost-benefit aspect of CR for actors involved in conventional wireless technology, as well as new entrants seeking new opportunities by entering the wireless industry.

Req. ID:	**B.cost**
Title:	Total cost
Text: *The total cost of a QoSMOS deployment in a defined target scenario shall not exceed the cost of a conventional system or the excess cost shall be compensated by tangible gains.*	
Related requirements:	A.flex; A.scale
Related QoSMOS WPs:	WP1: Business models analysis WP2: Complexity and flexibility of the architecture WP3: Complexity of protocol stack, sensing algorithms and required hardware WP4: Complexity and choice of PHY. WP5: Complexity and choice of QoS and mobility handling functions and protocols WP6: Data base method and cost
Scenario constraints:	Same relevance for all scenarios
Notes:	Cost issues must be assessed in all technical work and further used as input to the business model analysis

One of the spectrum sharing models that will be investigated in QoSMOS is spectrum trading, hence there must be support for this. There will be a need for spectrum trading between the various actors, e.g. mobile operators, broadcast operators, brokers, private or public users. Spectrum trading might be facilitated by intermediaries such as a spectrum broker or band manager, but can also be decentralized.

Req. ID:	**B.trading**
Title:	Spectrum trading
Text:	*The QoSMOS system should be able to support spectrum trading.*
Related requirements:	S.freq; A.reginfpol
Related QoSMOS WPs:	WP1: Spectrum micro trading metrics WP2: Architectural components for trading (e.g. intermediaries) WP5: Consider spectrum trading costs as part of service level agreements when admitting to service and allocating resources to a service WP6: Consider spectrum trading when managing spectrum. Spectrum manager supports spectrum evaluation
Scenario constraints:	Same relevance for all scenarios
Notes:	

5.2 Service-related requirements

In this section, the services delivered to the different users of the system are addressed. These are services delivered to the end users and means for enabling access to network resources by multiple service providers. Services delivered between different layers and entities in the QoSMOS system are covered indirectly via other requirements.

5.2.1 End user services

The final proof of the system's performance is the ability to provide services to the end users with acceptable quality at a reasonable cost.

Req. ID:	**B.userv**
Title:	End user services
Text:	*The QoSMOS system shall be able to provide services to end users with a quality meeting the end user's expectation when compared with that of conventional systems.*
Related requirements:	B.multiserv; P.traf; P.qos-iw; P.qmaintain; P.qpri; P.srvrestart; P.umob; P.term; P.drate; P.lat; P.cov; A.sec; A.flex
Related QoSMOS WPs:	WP2: Performance metrics definitions WP4: Efficient PHY and transceiver architecture WP5: QoS and mobility handling
Scenario constraints:	Same relevance for all scenarios
Notes:	

5.2.2 Multiple service providers

One business scenario of QoSMOS is that one actor is providing the technical infrastructure and others are using this for service provision. This can be the case for several of the defined QoSMOS scenarios listed in Table 2-1. Therefore, QoSMOS needs to be able to support wholesale mechanisms for service trading as well as the possibility of letting multiple service providers use the network for end user service provisioning.

Req. ID:	**B.multiserv**
Title:	Wholesaling and multiple service providers
Text:	*The QoSMOS system shall contain a mechanism to deal with wholesaling to several service providers*
Related requirements:	B.userv; P.traf; P.qos-iw; P,qmaintain; P.qpri; A.sec; A.flex
Related QoSMOS WPs:	WP2: Interfaces WP5: QoS and service level agreements (SLA); WP6: Inter-stakeholder interfaces and procedures;
Scenario constraints:	Same relevance for all scenarios
Notes:	

5.3 User terminals

From an end user's point of view, the terminal cost and benefit is an important differentiation factor. Terminal aspects include design properties like size and form factor, energy consumption and battery life, but they also include the interplay between network and terminal. The QoSMOS use case studies has concluded with four terminal types [9]:

Type A: Sensor with small transceiver, without user interface

Type B: Small phone or audio-only terminal, e.g. a voice enabled handset (cell-phone)

Type C: Smart-phone or similar device

Type D: Table, lap-top and larger equipment, i.e. a terminal with higher processing ability and sophisticated user interfaces.

Different terminal types are subject to constraints regarding technical capability and performance. Table 5-1 gives some indicative and non-exhaustive views on this, but they are not defined as requirements of each type. This should be a result of the market needs for each terminal type. The terms used in the table for power has not been quantified and is only used to indicate the differences. In the end, different power 'classes' can be defined, but the actual levels will be aligned with scenarios and frequency bands, in the specification work in WP2.

Req. ID:	**B.term**
Title:	Terminal types
Text:	*The QoSMOS system shall be able to recognize and support different terminal types and adapt to their capabilities in order to optimize the service performance.*
Related requirements:	S.ctxinfo; S.ctxresp; P.umob; P.term
Related QoSMOS WPs:	WP2: Ability to convey and store information about terminal types and capabilities related to subscribers WP3: Sensing protocol stack flexibility WP4: Physical layer capabilities WP5: Ability to recognize terminal constraints related to QoS WP6: Ability to recognize the availability to directly access the repositories (typically needed in distributed ad hoc network case)
Scenario constraints:	Different terminal types are relevant in different scenarios and use cases
Notes:	Different terminal types will have different capabilities that must be recognized by the network in order to deliver the services correctly and efficiently. For example, a video streaming service cannot be set up towards a terminal of type B or it is inefficient to allocate capacity a terminal could never exploit. Capabilities to support a specific spectrum range may also differ across terminals.

Table 5-1 QoSMOS terminal type capabilities (indicative)

Terminal type	Tx power	Spectrum support	Multi-mode capability
Type A	Low	Limited, only a single band	No
Type B	Low – medium	Several bands, consecutive channels	Also 2G, 3G
Type C	Low – medium	Several bands, able to combine several bands/channels	Also 2G, 3G, 4G and Wi-Fi
Type D	Medium – high	Several bands, able to combine several bands/channels	Also 2G, 3G, 4G and Wi-Fi

6 System operation related requirements

QoSMOS must comply with the constant change in global, regional and national regulations related to opportunistic spectrum access. Most of the requirements in this category can therefore in the light of identified frequency bands and regulatory situation. As explained in chapter 4, there is currently only one band identified for opportunistic access, and furthermore, it is only opened for use by the FCC in the US. The regulatory rules are also subject to changes based on market feedback policies. It comprises both functional and performance related requirements. Co-existence in the broader sense is treated here.

Req. ID:	**S.top**
Title:	Regulatory compliance
Text:	*The QoSMOS system shall be flexible and adaptable to differences in regulations given for the regions and markets in which it is intended to be deployed.*
Related requirements:	All requirements on system operation
Related QoSMOS WPs:	WP1: Business model analysis WP2: Interfaces towards geolocation databases and other regulatory policies. WP3: Performance of the sensing protocols and algorithms WP4: Performance of the PHY WP5: Resource management algorithms (manage diverse MAC and PHY settings; flexibly organise framing structures for example to accommodate sensing quiet periods) WP6: Database structure and context
Scenario constraints:	QoSMOS deployments are based on realizations of the system as defined in chapter 3 and will contain subsets of the complete ensemble of functions tailored to each specific scenario. Moreover, robustness to changes in regulations should also be supported at least to some extent.

6.1 Frequency independence

The QoSMOS frequency independence and dependence is elaborated in chapter 4. This requirement addresses the frequency agnostic nature of the QoSMOS system.

Req. ID:	S.freq
Title:	Frequency independence
Text:	*The QoSMOS system shall be designed to support any frequency band made available for opportunistic frequency access.*
Related requirements:	B.trading; P.spect; P.oob; P.drate; A.reginfpol; A.flex
Related QoSMOS WPs:	WP2: Internal interfaces WP3: Radio context acquisition WP4: Frequency capability signalled to/from transceiver WP5: Spectrum mobility WP6: Context information
Scenario constraints:	All possible frequency bands are not relevant for all scenarios, thus QoSMOS deployments should support only the bands relevant for the scenario and region.
Notes:	Realizations and deployments of the QoSMOS system is subject to constraints given by the scenario in which it is deployed and the regulations for the given region. Transceivers will be designed for one or more specific frequency bands, thus the transceiver's frequency capabilities must be accessible by the resource management entity.

6.2 Co-existence

It must be expected that QoSMOS deployments must co-exist with other QoSMOS deployments as well as, other opportunistic system deployments (see also subsection 8.1.1).

Co-existence is also mandatory towards incumbent users of the spectrum. The latter is treated in sections 6.4, 6.5 and 6.6. In this document, co-existence is understood as defined in chapter 3, however this is not strict. Co-existence aspects are also covered when discussing the interface requirements in section 8.1.

This requirement ensures that all the QoSMOS systems deployed in an area will have the capability to collaborate for sharing the spectrum resources efficiently.

Req. ID:	S.coex
Title:	Co-existence
Text:	*The QoSMOS system shall be able to coexist with other opportunistic spectrum access systems that might be deployed in relevant scenarios*
Related requirements:	S.intf; S.prot; S.geoloc; A.ifintra; A.ifinter; A.ifext; A.reginfpol; A.geoloc; A.mratsup; A.mrat-iw
Related QoSMOS WPs:	WP2: Interfaces definitions WP3: Sensing algorithms, sensitivity and protocols WP4: Frequency agility of transmitter and receiver; WP5 :Flexibility of the CM-RM (Both RC and RU [2]); Policy enforcements (execution) WP6: Context information, enhancing the information stored in the spectrum portfolio. Policy enforcements (rules)
Scenario constraints:	Same relevance for all scenarios
Notes:	Policy enforcement may be independent of the coexistence and also applicable to an isolated opportunistic spectrum access system. In case of coexistence, policies may include prevention of greedy users. Will also be covered in D5.2.

6.3 Context awareness

One enabler for the dynamic nature of a cognitive radio system is context awareness. This comprise the ability to collect the necessary information from sensing of the radio environment but also other types of context information from the spectrum portfolio data base and regulatory information repository.

Req. ID:	S.ctxinfo
Title:	Context information collection
Text:	*The QoSMOS system shall be able to collect information about the operating environment*
Related requirements:	B.term; S.ctxresp; S.sens; S.geoloc; P.qmaintain; P.srxsens; A.reginfpol; A.ifintra; A.ifinter; A.ifext; A.geoloc
Related QoSMOS WPs:	WP2: Interface support WP3: Sensing information availability WP4: Sensing receiver capabilities WP5: Acquisition of Context information (including spectrum sensing, when applicable). Dimensioning and prioritisation of reserve channels. Provision of usage and performance reports. Collection of physical mobility metrics. WP6: Context information organization
Scenario constraints:	Same relevance for all scenarios

Notes:	"Environment" can have a very wide interpretation, but should here be understood as any kind of external influence related to operation of the system. This can e.g. be user context, frequency situation and channel quality.

The full set of context information available is the basis for analysing and reacting to changes. Such changes can e.g. be the appearance of incumbents in the spectrum, a change in the regulatory policy, or changes of the conditions for spectrum use, e.g. price changes.

Req. ID:	**S.ctxresp**
Title:	Context based response capability
Text: *The QoSMOS system shall be able to analyse and react to changes in the environment*	
Related requirements:	B.term; S.ctxinfo; P.qmaintain; A.ifintra; A.ifinter; A.ifext; A.reginfpol
Related QoSMOS WPs:	WP2: Interface support WP3: Sensing information availability WP4: Transceiver agility WP5: Spectrum and physical mobility; resource management (including vacation and eviction) WP6: Opportunity detection
Scenario constraints:	Same relevance for all scenarios
Notes:	

6.4 Interference avoidance

A required property of a communication system operating in white spaces is the ability to avoid detrimental effects on transmissions of the incumbent user. Possible means for that, alternative or complementary, are database and spectrum sensing. Regulatory authorities may put demands on the use of those (see Section 6.6).

There is a strong relationship between the three requirements 'Interference avoidance' (S.intf, this section), 'Underlay operation' (S.ulay, section 6.5) and 'Incumbent protection' (S.prot, subsection 6.6.1). 'S.intf' could be seen as a 'parent' requirement for the two others, since it covers the ability to avoid disturbing incumbent use in a general sense. Then, S.ulay and S.prot covers the more specific cases for two spectrum sharing models, underlay and interweave.

Req. ID:	**S.intf**
Title:	Interference avoidance
Text: *All QoSMOS devices exploiting opportunistic spectrum use in white spaces shall avoid interference to incumbent communications.*	
Related requirements:	S.coex; S.ulay; S.prot; S.sens; S.pwr; P.srxsens; P.crxsens; A.reginfpol;

Related QoSMOS WPs:	WP3: Sensing performance, e.g. the delay between occurrence of incumbent user(s) and detection by CR device WP4: Transmitter power control WP5: Transmitter power control. Policy enforcement (execution). Resource usage algorithms for distributed power control WP6: Proper detection, classification and management of spectrum opportunities
Scenario constraints:	Same relevance for all scenarios
Notes:	There might be different regulatory requirements in different regions and for utilizing different frequency bands.

6.5 Underlay operation

Underlay operation means that the opportunistic radio transmits in the same band as the incumbents, but at power levels low enough to avoid disturbances of the incumbents' receiver. In this case, the incumbents receive the opportunistic signal at levels similar or lower than noise. Ultra Wideband (UWB) is a technology where underlay strategy was applied. Spreading the energy over very large bands reduces 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 and/or very low data rates.

Req. ID:	**S.ulay**
Title:	Underlay operation
Text:	*The QoSMOS system should comply with regulations for underlay communications in relevant regions and markets.*
Related requirements:	S.intf; S.pwr; A.reginfpol
Related QoSMOS WPs:	WP4: Transmit power control WP5: QoS management according to requirements for underlay operations (underlay implies generally lower available data rates, or extremely short ranges) WP6: Definitions of the data structures and descriptions of these
Scenario constraints:	This requirement is only relevant for short range scenarios due to the limited transmitter power.
Notes:	Currently, only FCC (US) has defined power limits for underlay communications using UWB techniques for frequencies below 10.5 GHz. See Table 6-1. Opportunistic systems may define a limitation on their transmit power in order to comply with the constraints on interference at possible incumbent receivers.

Table 6-1 Current limits for underlay transmissions

Region	Frequency band	Power spectral density (PSD)	Other constraints
FCC [10]	3.1 - 10.6 GHz	-41.3 dBm/MHz	*UWB devices must be able to detect the presence of WiMAX systems operating at 3.5GHz and switch off whenever such WiMAX transmission is detected (Detect and Avoid mechanism)*

6.6 Interweave operation

The UHF TV band is the only example where regulators have strongly considered the operation of opportunistic usage. This originated in most cases from the analogue TV switch-over towards full Digital Terrestrial Television (DTT). Thanks to the better spectral efficiency of DTT over its analogue counterpart, several countries have now performed this transition. Therefore the specific requirements in this section are mostly possible to interpret for TV white space operation in the 470 – 790 MHz (TVWS) band, defined as QoSMOS band A (see chapter 4). Interweave operation means dynamic exploitation of spatial and temporal spectral opportunities in a non-interfering manner. This spectrum sharing model is called overlay by IEEE P1900 [11], but overlay is sometimes used to describe another spectrum sharing model [12]. We use the definition in chapter 3, which is consistent with QoSMOS deliverable D6.1 [12].

This basically translates into allowing opportunistic transmission only when and where incumbent signal is absent (frequency, time and location). It can be noted that the Detection and Avoidance mechanisms introduced for the coexistence of UWB with WiMAX [10] turn the underlay communication to operate in an interweave mode (see above, section 6.5).

6.6.1 Systems to avoid

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

- Before setting an opportunistic transmission: detection of any incumbent system presence in the area where opportunistic transmission is intended. 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 opportunistic system.
- When the opportunistic transmission is set: tracking the potential apparition of an incumbent signal and escape from the band whenever this situation occurs.

At the moment, the 470 – 790MHz band is the one which regulators consider most seriously for interweave operation of opportunistic systems. CEPT [6] gives a list of the systems that must be protected from emissions of opportunistic systems operating in ‘white spaces’, in the band 470 – 790 MHz in Europe.

Some existing medical systems may operate in the TV bands without license. Although “illegal” and thus not considered a system that must be protected, nobody really wants to harm these devices and measures are required to protect these actively, e.g., by emitting protective beacons. These systems will most likely not appear in any spectrum data base, and sensing will be the only way to protect these.

Req. ID:	S.prot
Title:	Incumbent protection
Text:	*The QoSMOS system shall be able to comply with the protection requirements of the operating frequency band in different regions and markets.*
Related requirements:	S.coex; S.intf; S.sens; S.geoloc; S.pwr; P.chchg; P.spect; P.oob; P.drate; A.reginfpol; A.geoloc
Related QoSMOS WPs:	WP3: Framework for sensing and the sensing algorithms WP4: Physical layer modulation and adjacent band/channel power WP5: Dynamic resource management and access; scheduling WP6: Data bases must contain the relevant information. Policy enforcement
Scenario constraints:	Same relevance for all scenarios
Notes:	This form of protection means to avoid the use of the spectrum resource when it is in occupied by the incumbent. It would also include the ability to vacate the channel and the suspension of periodic idle-mode reporting to the network. At the moment, the only band which is considered for interweave operation is the 470 – 790 MHz band (TVWS), defined as QoSMOS band A. CEPT [6] has identified the incumbent (incumbent) services which must be protected in this band. See Table 6-2.

Table 6-2 Protected services in the 470-790 MHz band (QoSMOS band A)

Region:	Protected service
CEPT [6]	*Broadcasting service (BS) in the band 470-790 MHz;*
	Program Making and Special Event (PMSE) services in the band 470-790 MHz; because low power wireless microphones signal detection is challenging, and also because they may not always subscribe to a database in real time
	Radio Astronomy Service (RAS) stations operating in the band 608-614 MHz
	Aeronautical Radionavigation Service (ARNS) operating in the band 645-790 MHz
	Mobile/Fixed services in bands adjacent to the band 470-790 MHz

6.6.2 Incumbent detection with sensing

Incumbent protection comprises techniques for limiting the impact of interference. A pre-requisite is to detect the presence of incumbents by sensing. This will be the only option for limiting interference towards certain medical systems operating “illegally” in the TVWS (see subsection 6.6.1)

Req. ID:	**S.sens**
Title:	Sensing for incumbent detection
Text: *The QoSMOS system should support sensing for incumbent detection.*	
Related requirements:	S.ctxinfo; S.prot; P.srxsens; A.reginfpol
Related QoSMOS WPs:	WP3: Framework for sensing and the sensing algorithms WP5: Schedule quiet periods for sensing with QoS degradation kept within given bounds. WP6: Detect, classify and manage opportunities based on sensing information. Enforcement of policies.
Scenario constraints:	Same relevance for all scenarios
Notes:	For the current situation in the TVWS (QoSMOS band A) this is not mandatory. Due to the fact that opportunistic usage is mainly considered in this band, the figures in Table 6-3 are provided for these bands in different areas.

Table 6-3 Sensing requirements for incumbent detection in the 470-790 MHz band (QoSMOS band A)

	FCC 2009 [3]	**FCC 2010 [5]**	**Ofcom 2009 [4]**	**Ofcom 2010 [15]**	**CEPT 2010 [6]**
DTT detection sensitivity	-114 dBm in 6MHz	Not required	-114 dBm in 8 MHz	Not required	Should not be required
PMSE (wireless microphone detection sensitivity)	-114 dBm in 200 kHz	Not required	-126 dBm in 200 kHz	Not required	Should not be required

6.6.3 Location based incumbent detection

The second approach to detect the presence of incumbents is though an indirect approach based on geolocation. With this strategy, the opportunistic radio first determines its own location and then asks a database about the channel allowed for opportunistic usage at that place. Provided that the database, or spectrum portfolio, is updated about the incumbent operation, it can answer the request by pointing to available channels and power levels allowed in each of them. It could even allow usage until some time deadline is met. For the same reasons as stated in the previous case, the location accuracy is linked to the allocated power for the opportunistic system.

Req. ID:	**S.geoloc**
Title:	Geolocation accuracy
Text:	*The QoSMOS system shall support geolocation of its wireless nodes (base stations, access points, terminals etc.) according to requirements in different regions and markets.*
Related requirements:	S.coex; S.ctxinfo; S.prot; A.reginfpol; A.geoloc
Related QoSMOS WPs:	WP2: Interfaces towards geolocation data bases WP3: Alternative methods for combining sensing and geo-location WP5: Services, mobility and update rate WP6: Data structures
Scenario constraints:	The method used for acquiring position info will probably differ between the scenarios.
Notes:	The accuracy required for geolocation systems in the USA, the UK and Europe in the 470-790MHz band (QoSMOS band A), is given in Table 6-4. In the USA, the FCC requests geolocation means to be present in all fixed and Mode II devices (see 6.6.4 hereafter), 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.

Table 6-4 Geolocation accuracy for incumbent protection in the 470-790 MHz band (QoSMOS band A)

	FCC 2009 [3]	**FCC 2010 [5]**	**Ofcom 2009 [4]**	**Ofcom 2010 [15]**	**CEPT 2010 [6]**
Geolocation accuracy	50 m	50 m	100 m	Not specified	Not specified yet

6.6.4 Maximum allowed power

Another part of the incumbent protection strategy is to adapt the output power in order to limit unnecessary emissions.

Req. ID:	**S.pwr**
Title:	Transmitter power
Text: *The QoSMOS system shall operate with a transmitter power according to regulations in different regions and frequency bands.*	
Related requirements:	S.intf; S.ulay; S.prot; P.crxsens; P.cov; A.reginfpol
Related QoSMOS WPs:	WP4: Transmitter design WP5: Radio resource management; QoS management WP6: spectrum manager considers maximum transmit power
Scenario constraints:	The current regulations in the 470-790 MHz band do not distinguish between deployment scenarios. In the future, different frequency bands accompanied by different transmitted power limits may be used in different scenarios.
Notes:	As for all requirements regarding interweave transmission, only values for the 470-790 MHz band (QoSMOS band A) exists for the moment. Table 6-5 lists the maximum allowed power limits defined by FCC, Ofcom and CEPT. Opportunistic devices may be able to adapt the transmitter power if regulations change, or if it is intended for use in different regions.

Table 6-5 lists the maximum allowed power limits in different regions. In this context we define the term in-band to be the actual channel used by the QoSMOS transceiver. Consequently out-of-band refers to other channels. This is further detailed by QoSMOS in D2.2 [2]. This differs from the understanding used for cellular system, where in-band refers the whole band regulated for the system, while out-of-band means outside this band.

Table 6-5 Maximum power allowed in the 470-790 MHz band for cognitive radios (QoSMOS band A)

	FCC 2009 [3]	**FCC 2010 [5]**	**Ofcom 2009 [4]**	**Ofcom 2010 [15]**	**CEPT 2010 [6]**
Transmit power (fixed) EIRP	4W	4W	100mW	Not mentioned	Local specific
Transmit power (portable) EIRP	100mW	100mW	100mW	Not mentioned	Local specific
Transmit power in adjacent bands to DTT signals	40mW	40mW	20mW	Not mentioned	Local specific
Out of band radiation	-55dBm under the in-band level	-55dBm under the in-band level			

6.7 Robustness and security

Performance of communication is affected by the presence of other communication systems and other electromagnetic emitters. A cognitive communication system shall be able to detect the presence of incumbents, so it should be able to detect the presence of other opportunistic users as well, thus potentially reducing the impact of destructive interference of coexisting communication systems.

Req. ID:	**S.rob**
Title:	Robustness
Text:	*The QoSMOS system should be able to detect signals other than incumbent and possibly other sources of electro-magnetic fields in the operating frequency range.*
Related requirements:	S.mal;
Related QoSMOS WPs:	WP3: Selection of adequate sensing algorithms (e.g. energy detection, cyclostationary detection) WP4: transceiver. Performance estimations. Planning use of spectrum WP5: services; QoS maintenance WP6: proper detection, classification and management of spectrum opportunities
Scenario constraints:	Same relevance for all scenarios
Notes:	

The spectrum resource used for communication should provide sufficient quality of service. A cognitive communication system is able to select the operating channels among a set of channels. It may therefore be able to move out from a highly disturbed or unusable resource. A method for enabling this is to provide a robust control channel for network coordination.

Req. ID:	**S.cch**
Title:	Common channel
Text:	*The QoSMOS system shall be able to provide or establish a robust logical channel for network coordination.*
Related requirements:	A.flex;
Related QoSMOS WPs:	WP2: Interface support WP5: Control signalling. Network coordination. WP6: Should be notified in the spectrum portfolio
Scenario constraints:	Same relevance for all scenarios
Notes:	This could be a dedicated physical channel or non-intrusive communication methods, such as underlay spectrum sharing with very low transmit power

Malicious use of the system may occur. This can stem from malfunctioning devices or from deliberate attacks. A device may be misbehaving either because its user behaves malicious or because the device is broken. Many repeated requests could be either a Denial of Service (DoS) attack or simply a device missing feedback. Here malfunctioning is the same as broken.

Req. ID:	**S.mal**
Title:	Malicious use
Text:	*The system shall be able to detect attacks and defective devices and be robust to those misbehaviours.*
Related requirements:	A.sec
Related QoSMOS WPs:	WP4: Robustness of air interface WP5: Device association, barring of devices not complying with ‘etiquette’ WP6: Attacks to and malicious use of database
Scenario constraints:	Same relevance for all scenarios
Notes:	

7 Performance related requirements

The performance of the QoSMOS system must be comparable to conventional systems. Cognitive radio should not only be viable in areas of spectrum shortage, but also be competitive to conventional systems where there is licensed spectrum available. These are prerequisites for comparing business cases (ref section 5.1). Technical performance is a part of this, but it has to been seen in light of the business case and customer segment. Performance can e.g. be traded off for low price. User expectation is a yardstick which should lie behind most performance requirements. This is often defined by the term Quality of Experience (QoE), a subjective measure of a customer's experiences with a vendor or service provider. It is related to but differs from Quality of Service (QoS), which attempts to objectively measure the service delivered.

Req. ID:	**P.top**
Title:	Technical performance
Text: *The QoSMOS system's technical performance should be good enough to meet users' expectations of the service delivered.*	
Related requirements:	All performance related requirements
Related QoSMOS WPs:	Relevant for all work in QoSMOS
Scenario constraints:	The requirement is relevant for all scenarios, however, the target performance may be different in the different scenarios

7.1 QoS related requirements

The QoS framework is defined in QoSMOS WP5, and detailed requirements for these are defined in D5.1 [16]. They have been taken as base for the consolidated requirements in this section.

One of the pillars of QoSMOS is the ability of managing Quality of Service (QoS). The consequences are that the system must have mechanisms for this and there must be some basic rules behind them. Such rules are related to prioritizing traffic. The mechanisms deal with maintaining QoS for the existing users under changing conditions and context.

7.1.1 Traffic classes

This requirement will ensure that the QoSMOS system contains the necessary technical solutions to provide managed QoS with different traffic classes. These will be defined in WP5.

Req. ID:	P.traf
Title:	Traffic classes
Text: *The QoSMOS system shall support the differentiation between traffic classes.*	
Related requirements:	B.userv; B.multiserv; P.qos-iw; P.qmaintain; P.qpri; P.lat;
Related QoSMOS WPs:	WP2: Interface support WP5: Definitions of QoSMOS traffic classes; ability to identify the nature of information WP6: Context information
Scenario constraints:	QoSMOS deployments in certain scenarios may be allowed to support only a subset of the total amount of traffic classes, dependent on the uses cases which are to be served.
Notes:	

7.1.2 QoS when interworking

Interworking with other RATs is an important feature for QoSMOS success. This comprises both conventional RATs (e.g. 3GPP, Wi-Fi etc.) and other cognitive RATs. Handover and service mobility should be transparent towards the QoS of traffic classes between the RATs. The need for interfaces to support this is specified in section 8.1, while it also affects the need for sufficient co-existence mechanisms as stated in section 6.2. QoSMOS must define its own set of QoS classes, but a mapping towards legacy systems (e.g. 3GPP and IEEE) must be provided as part of the interworking functionality.

Req. ID:	P.qos-iw
Title:	QoS interworking
Text:	*The QoSMOS system shall support QoS classes which can be mapped to classes defined in other widespread RATs.*
Related requirements:	B.userv; B.multiserv; P.traf; P.qmaintain; P.qpri; P.srvrestart; P.umob; P.drate; P.lat; A.ifintra; A.ifinter; A.ifext; A.mratsup; A.mrat-iw;
Related QoSMOS WPs:	WP2: Interface support WP5: Translation tables towards other systems. Definitions of QoSMOS traffic classes; vertical handover; end-to-end issues (especially concerning priorities). WP3: User behaviour and radio environment. WP6: Manage and characterize spectrum in presence of QoS
Scenario constraints:	Same relevance for all scenarios
Notes:	Different systems have different definitions of QoS classes. It is therefore necessary for QoSMOS to define mappings to some of these. We may also need to enhance these. Supporting a QoS class means also complying with its data rate and latency requirements, for example. It is necessary to be careful when addressing this requirement, because it may require some effort as seen from other RATs.

7.1.3 Managing QoS

Managed QoS aims at controlling the delivered user experience. QoS shall be according to service level agreements between the involved parties, and the system should seek to maintain the agreed service level. In technical terms this relates to the traffic and QoS classes.

Req. ID:	P.qmaintain
Title:	Maintaining QoS
Text:	*The QoSMOS system should maintain the agreed QoS level of the traffic under changing conditions*
Related requirements:	B.userv; B.multiserv; S.ctxinfo; S.ctxresp; P.traf; P.qos-iw; P.qpri; P.srvrestart; A.ifintra; A.ifinter; A.ifext; A.flex;
Related QoSMOS WPs:	WP4: Channel impairment mitigation techniques WP5: Resource management algorithms (including eviction and handover); context acquisition
Scenario constraints:	Same relevance for all scenarios, however, the range of QoS classes may differ for QoSMOS deployments in the different scenarios
Notes:	Possible resource shortage conflicts may have the consequence that a renegotiation of the service level may be necessary. Admission control will also depend on QoS requirements and on the channel capacity provided by the available resources.

Situations will most likely occur in which the resource availability will be less than the demand. In this case, the QoSMOS system must be able to perform the necessary prioritizing of the traffic coming from different users.

Req. ID:	**P.qpri**
Title:	QoS priority
Text:	*The QoSMOS system shall make priority for traffic with a higher agreed QoS level according to resource availability*
Related requirements:	B.userv; B.multiserv; P.traf; P.qos-iw; P.qmaintain; P.srvrestart; P.chchg;
Related QoSMOS WPs:	WP5: Resource management algorithms (including implementation of different priorities and ability to map information to them)
Scenario constraints:	Same relevance for all scenarios
Notes:	This can e.g. be the case of prioritizing sensing information to be conveyed.

In cases where the service is disrupted due to changes in resource availability or when traffic belonging to a higher QoS class is prioritized, it should be possible to re-establish also lower priority traffic within certain time limits

Req. ID:	**P.srvrestart**
Title:	Service reestablishment
Text:	*The QoSMOS system should be able to re-establish a disrupted service within an agreed time limit provided the necessary resources become available*
Related requirements:	B.userv; P.qos-iw; P.qmaintain; P.qpri; P.chchg
Related QoSMOS WPs:	WP5: Resource management,
Scenario constraints:	Same relevance for all scenarios
Notes:	This implies that the necessary handles for a service should be maintained also when the service is disrupted. This can e.g. be due to unforeseen changes, like a missed handover or by forced eviction due to incumbent appearance.

7.2 Mobility related requirements

Another pillar of QoSMOS is the mobility support, which includes the physical layer's ability to handle fast fading and multipath propagation as well as the handover functionality on the link layer. Different kinds of mobility can be defined. The mobility handling is defined in QoSMOS WP5, and detailed requirements for these are defined in D5.1 [16]. These have been taken as base for the consolidated requirements in this section. In QoSMOS WP5 a distinction is done between physical mobility and spectrum mobility, the latter being e.g. the change of an operating channel not necessarily associated with physical movement. Regarding physical mobility, different mobility classes can be defined, e.g. related to physical speed. Mobility specific requirements address the different aspects of mobility in QoSMOS and which functionalities are needed.

Below, we have made a distinction between *terminal* mobility and *user* mobility. This may seem artificial, since usually they will coincide. However, we can foresee that user mobility maybe across several terminals, e.g. that service may be handed over from one terminal to another.

7.2.1 Mobile users

This requirement addresses the basic mobility handling functionality needed to provide sufficient service continuity for the end-user.

Req. ID:	**P.umob**
Title:	User mobility
Text: *The QoSMOS system shall be able to support mobile users*	
Related requirements:	B.userv; B.term; P.qos-iw; P.chchg; A.flex;
Related QoSMOS WPs:	WP4: Physical layer agility WP5: Physical mobility and handover issues in relation with QoS; identification of the service regardless of any association with a terminal WP6: Context information and changes to this
Scenario constraints:	It is relevant for all scenarios; however, the actual degree of mobility will differ.
Notes:	The user mobility is not the same as terminal mobility, but that the user is able to move his/her service experience from one terminal to another.

7.2.2 Terminal mobility

Mobility is an important parameter in QoSMOS and the system should ensure respectable QoS even in mobile scenarios. 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, the physical terminal mobility is limited. Fast mobility and achievable throughput or data rate are contradictory requirements and must be seen combined. There is a trade-off between a high throughput and high mobility. Usually you cannot have high data rates and high physical mobility simultaneously.

Req. ID:	P.term
Title:	Terminal mobility
Text:	*The QoSMOS system shall be able to handle terminal mobility according to the scenario.*
Related requirements:	B.userv; B.term; P.qmaintain; P.hosupp; P.chchg; P.drate; A.mratsup; A.mrat-iw; A.flex;
Related QoSMOS WPs:	WP3: Sensing performance, e.g. the delay between occurrence of incumbent user(s) and detection by CR device WP4: Physical layer ability to handle the mobile channel WP5: Physical mobility and handover issues in relation with QoS; identification of the service associated with the terminal WP6: manage and characterize spectrum in presence of mobility
Scenario constraints:	Different terminal mobility support is foreseen in the different scenarios. Support for handover due to physical mobility may not be applicable in all scenarios. This is most likely to be the case for the dynamic backhaul scenario
Notes:	High mobility requirements can be traded off for higher throughput where applicable and when it is needed.

7.2.3 Handover support

Terminal mobility over a larger geographical area implies that the available resources change. This is mostly due to location change, which implies that the conditions for opportunistic access change. It is also the usual change in radio reception quality due to changes in the link budget.

Req. ID:	P.hosupp
Title:	Handover support (physical mobility)
Text:	*The QoSMOS system shall support handover to ensure seamless connectivity when the terminal is moving across the system covered areas.*
Related requirements:	P.qmaintain; P.umob; P.term; A.mrat-iw; A.flex;
Related QoSMOS WPs:	WP5: Resource management and mobility WP6: Context information and management
Scenario constraints:	Support for handover due to physical mobility may not be applicable in all scenarios. This is most likely to be the case for the dynamic backhaul scenario.
Notes:	

Handover may also be necessary due to other reasons than that the radio link quality is deteriorated. For a cognitive radio system based on opportunistic access in white spaces, the appearance of an incumbent or context changes are most relevant.

Req. ID:	P.chchg
Title:	Handover support (spectrum mobility)
Text:	*The QoSMOS system should be able to force handover to another channel when required by changes in the radio environment.*
Related requirements:	S.prot; P.qmaintain; P.qpri; P.srvrestart; P.term;
Related QoSMOS WPs:	WP5: Resource management and mobility WP6: Context information and management
Scenario constraints:	Same relevance for all scenarios
Notes:	Such a change can be triggered by the appearance of an incumbent. Another example is the need for optimizing spectrum usage due to changes in offered traffic.

7.3 Spectrum utilization

The demand for increased throughput and data rates within given bandwidths demand more efficient use of the spectrum. In state-of-the-art mobile broadband systems (i.e. LTE and Mobile WiMAX), the spectrum efficiency is approaching 4 bits/s/Hz in the downlink and 2 bits/s/Hz in the uplink, however the highest spectrum efficiency is only achievable in high SNR conditions. A CR system should be able to utilize the spectrum with high efficiency. Since opportunistic spectrum access is more variable and dynamic, it is of even more importance to ensure efficient use 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).

Req. ID:	P.spect
Title:	Spectrum utilization
Text:	*The peak spectrum efficiency of the QoSMOS physical layer should be as good as or better than current state-of-the art mobile broadband systems.*
Related requirements:	S.freq; S.prot; P.oob; P.drate;
Related QoSMOS WPs:	WP4: Efficiency of the physical layer WP5: Efficient signalling and protocols to minimise overheads
Scenario constraints:	The need for high spectrum efficiency is not equal in all scenarios. In the cellular extension and cognitive femtocell scenarios the spectrum efficiency should approach the current state-of-the-art, but in others, e.g. ad hoc networks this requirement may be more relaxed. In an emergency ad hoc network robust links will be important, and this usually means larger overhead in the physical layer protocol.
Notes:	Upper layer (average) spectrum efficiency will most likely be lower due to increased overhead etc.

7.4 Out-of-band radiation

The out of band radiation is an important yard stick in QoSMOS system performance evaluation. The QoSMOS system will be working in the white spaces where it is mandatory that the opportunistic users have a minimal interference impact on the incumbent. To efficiently use the vacant spectrum, we need to have innovative transceiver architectures so that the QoSMOS users don't interfere with the legacy TV channels. For this purpose, various pulse shaping filters are being used in the transceiver, as compared to rectangular filters, root-raised cosine filters give lower side lobe and this practically eliminates the interference from the opportunistic users. OFDM system, although being extremely flexible, will cause serious interference to the legacy users. For this innovative PHY techniques are being investigated. To meet the regulatory requirements, low out-of-band leakage is extremely important for the QoSMOS system. The signal generation should have sharp spectral roll-off to ensure the best spectral occupation, otherwise frequency guard intervals will be needed impacting the spectral efficiency significantly.

Req. ID:	**P.oob**
Title:	Out-of-band radiation
Text: *The physical layer design of the QoSMOS system shall seek a low out-of-band radiation*	
Related requirements:	S.freq; S.prot; P.spect;
Related QoSMOS WPs:	WP4: Physical layer modulation and pulse shaping techniques
Scenario constraints:	Same relevance for all scenarios
Notes:	The actual values for out-of-band radiation levels are given by regulators as transmitter spectrum masks. Values will vary in different markets and regions and will also depend on the frequency band.

7.5 Data rates

The QoSMOS system will be designed to operate in very different and varied scenarios. The indoor/outdoor, short/long range use cases have different demands for data rates.

Req. ID:	**P.drate**
Title:	Data rates
Text:	*The QoSMOS system should be able to provide the data rates needed to satisfy the QoS demands for the different use cases.*
Related requirements:	B.userv; S.freq; S.pwr, P.qos-iw; P.term; P.spect; A.mratsup; A.flex;
Related QoSMOS WPs:	WP4: The physical layer and transceiver architecture design. WP5: Radio resource management WP6: Management of spectrum and aggregation of bands to provide sufficient data rates
Scenario constraints:	The data rates to be provided will vary depending on the use case that is serviced. The QoSMOS transceiver implementation cannot be one-size-fits-all, but has to be according to the deployment scenario. The short range scenarios (cognitive ad hoc and femto-cell) will put higher demands on the data rate than cellular extension and direct terminal-to-terminal. The same will probably be for the rural broadband.
Notes:	The achievable data rates are tightly related to both transmitter power and available spectrum and corresponding spectrum efficiency. Therefore it is not possible to quantify the requirements, but the physical layer and its radio resource management (RRM) must be flexible enough to support high data rates when sufficient physical bandwidth resources are present.

7.6 Latency

Achieving seamless inter-operability with the existing network components is essential to improve the consumer experience. Services and applications like video streaming, call transfer with fast handoff, uninterrupted social networking connectivity, gaming etc. calls for low latency, which plays an important role in maintaining the quality of service of the 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.

Latency in a packet-switched network is measured either one-way or round-trip. One-way latency for a link can be more strictly defined as the time from the start of packet transmission to the start of packet reception. In a mobile system we typically distinguish between C-(control) plane and U-(user) plane latency. C-plane latency is normally the transition time for a terminal from idle mode to camped (or active) state, and is longer than the U-plane latency which obeys the general definition above, i.e. the terminal is already in active state.

Req. ID:	P.lat
Title:	Latency
Text:	*The QoSMOS system should be able to provide the latencies needed to satisfy the QoS requirements for the different use cases.*
Related requirements:	B.userv; P.traf; P.qos-iw; A.mratsup; A.flex;
Related QoSMOS WPs:	WP4: Transceiver architecture. WP5: Radio resource management and QoS; access protocol WP6: Management of spectrum should be within time limits
Scenario constraints:	Different QoSMOS scenarios will require different latency figures, depending on the use cases they serve
Notes:	As an example, latency requirements and performance for 3GPP LTE is 100 ms and 5 ms for the C-plane and U-plane. Since a CR system will need more signalling in order to establish a connection (identifying vacant spectrum, negotiating price etc.) we cannot be sure that QoSMOS is able to meet the same requirements.

7.7 Sensitivity

Receiver sensitivity is a measure of how well the receiver can detect a low-level signal, and is an indicator of the noise figure of the receiver. In QoSMOS, we have two logical receivers; the sensing receiver used for incumbent detection, and the communication receiver. Whether these are the same is dependent on the actual design and implementation.

The QoSMOS transceiver needs to have high sensitivity both for the sensing and also for the communication block. However the requirements for these two blocks have different goals.

The QoSMOS system will have to sense the spectrum for any available white space, with the constraint that the opportunistic users should not interfere with the incumbent. This is a direct consequence of the regulatory requirements of subsection 6.6.2.

Req. ID:	P.srxsens
Title:	Sensing receiver sensitivity
Text:	*The sensing receiver sensitivity of the QoSMOS system should be good enough to comply with regulatory requirements*
Related requirements:	S.ctxinfo; S.sens
Related QoSMOS WPs:	WP3: sensing receiver sensitivity and reliable sensing algorithms WP4: Noise figure of the receiver front-end WP5: QoS and network coordination
Scenario constraints:	The required sensitivity will vary between different scenarios.
Notes:	Instead or in addition to sensing receiver sensitivity, more reliable sensing algorithm may require measurements from more sensors and/or more frequent measurements.

The communication receiver's performance is guided by the need to obtain as good a link budget as possible. This may also stem from a regulatory requirement on minimizing the field strength, and will often be quantified in conformance specifications as part of standards.

Req. ID:	**P.crxsens**
Title:	Communication receiver sensitivity
Text:	*The communication receiver sensitivity of the QoSMOS system should be good enough to support the necessary ranges of the different scenarios and to minimize the required field strength for error free reception.*
Related requirements:	S.intf; S.pwr; P.cov;
Related QoSMOS WPs:	WP4: Noise figure of the receiver front-end. ADC resolution
Scenario constraints:	The required sensitivity will vary between different scenarios.
Notes:	

7.8 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. This could e.g. stem from changes in the incumbent use and also the entry of other CR systems within the coverage area.

Req. ID:	**P.cov**
Title:	Coverage
Text:	*The QoSMOS system should be able to provide in each scenario the corresponding expected coverage.*
Related requirements:	B.userv; S.pwr; P.crxsens; A.mratsup; A.flex;
Related QoSMOS WPs:	WP3: Sensing sensitivity and geolocation resolution WP4: The physical layer design
Scenario constraints:	The expected coverage differs between scenarios from a few meters in the case of ad hoc networks and femto-cell deployments up to tens of kilometres for rural broadband.
Notes:	Remarks, explanations, interpretations, examples

8 Architecture and complexity related requirements

The architecture requirements are, by definition, the requirements identifying some additional constraints on top of the system and functional requirements for the definition of the QoSMOS architecture. These requirements mainly affect WP2 activity. Furthermore, it is important that the QoSMOS system is as simple and modular as possible, both for supporting a low cost deployment, but also ensuring flexibility and scalability.

Req. ID:	**A.top**
Title:	Architecture and Complexity
Text:	*The QoSMOS architecture shall ensure complying with other external systems and ensure flexibility and scalability*
Related requirements:	All architecture and complexity related requirements
Related QoSMOS WPs:	Relevant for all work in QoSMOS
Scenario constraints:	QoSMOS deployments will contain subsets of the complete ensemble of functions tailored to each specific scenario.

8.1 Interfaces with external systems

Co-existence between different systems shall be ensured, and it encompasses different aspects. Operational co-existence requirements are given in section 6.2. In this section, the consequential requirements for the architecture and system interfaces are given.

8.1.1 Coexistence with other opportunistic systems

Several opportunistic systems could exist in the same area. The QoSMOS architecture shall allow interworking with all other opportunistic systems:

- Other QoSMOS systems belonging to the same operator
- Other QoSMOS systems belonging to another operator
- Other opportunistic systems belonging to another operator

Req. ID:	**A.ifintra**
Title:	Interfaces
Text:	*The QoSMOS architecture shall ensure coexistence between the QoSMOS system and all QoSMOS opportunistic systems in the same operator domain*
Related requirements:	S.coex; S.ctxinfo; S.ctxresp; P.qos-iw; P.qmaintain; A.ifinter; A.ifext; A.mratsup; A.mrat-iw
Related QoSMOS WPs:	WP2: Interface support WP6: Enabling coexistence of players (i.e., licensed and license-exempt users)
Scenario constraints:	Same relevance for all scenarios
Notes:	Functionalities needed for this requirement are also implied by requirements belonging to incumbent protection (see chapter 6), and associated to similar features.

Req. ID:	**A.ifinter**
Title:	Interfaces
Text:	*The QoSMOS architecture shall ensure coexistence between the QoSMOS system and all QoSMOS opportunistic systems operated by another operator*
Related requirements:	S.coex; S.ctxinfo; S.ctxresp; P.qos-iw; P.qmaintain; A.ifintra; A.ifext; A.mratsup; A.mrat-iw;
Related QoSMOS WPs:	WP2: Interface support WP6: Enabling coexistence of players (i.e., licensed and license-exempt users)
Scenario constraints:	Same relevance for all scenarios
Notes:	Functionalities needed for this requirement are also implied by requirements belonging to incumbent protection (see chapter 6), and associated to similar features.

Req. ID:	A.ifext
Title:	Interfaces
Text:	*The QoSMOS architecture shall ensure coexistence between QoSMOS system and other opportunistic systems (pertaining to another owner).*
Related requirements:	S.coex; S.ctxinfo; S.ctxresp; P.qos-iw; P.qmaintain; A.ifintra; A.ifinter; A.mratsup; A.mrat-iw
Related QoSMOS WPs:	WP2: Interface support WP6: Enabling coexistence of players (i.e., licensed and license-exempt users)
Scenario constraints:	Same relevance for all scenarios
Notes:	Functionalities needed for this requirement are also implied by requirements belonging to incumbent protection (see chapter 6), and associated to similar features.

8.1.2 Regulation information and policies

QoSMOS system may be constrained by regulation rules and policies. As such there shall be interfaces allowing the QoSMOS system to get these rules and policies from an external entity.

Req. ID:	A.reginfpol
Title:	Interface with regulation information
Text:	*The QoSMOS architecture shall enable access to regulation information and policies.*
Related requirements:	B.trading; S.freq; S.coex; S.ctxinfo; S.ctxresp; S.intf; S.ulay; S.prot; S.sens; S.geoloc; S.pwr; A.geoloc; A.sec;
Related QoSMOS WPs:	WP2: Interfaces towards regulatory policies system. WP5: Acquisition (at CM-RM) of corresponding information (from CM-SM); update rate in mobile scenarios WP6: The interface for exchanging Regulation Policies shall be enabled through CM-SM. Implementing spectrum etiquette and enforcement of policies.
Scenario constraints:	Same relevance for all scenarios
Notes:	

8.1.3 Geolocation databases

As an important co-existence mechanism identified by some regulators, a white space database shall be accessible to the QoSMOS system. This should be via an interface identified when 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.

Req. ID:	A.geoloc
Title:	Interface with geolocation database
Text:	*The QoSMOS architecture shall allow collecting information (whitespace usage) from a geolocation database and shall allow updating if required by the regulatory rules*
Related requirements:	S.ctxinfo; S.prot; S.geoloc; P.spect; A.reginfpol; A.sec;
Related QoSMOS WPs:	WP2: Interfaces towards geolocation databases WP3: Time needed for sensing and reporting (algorithms and protocol) WP5: Update rate in mobile scenarios. WP6: The interface for exchanging spectrum context information from geolocation database shall be enabled by CM-SM (spectrum management aspects. and potential update of data base of frequency band describing the spectrum available for opportunistic operation of a wireless network)
Scenario constraints:	Same relevance for all scenarios
Notes:	

8.1.4 Multi-RAT interworking

The QoSMOS systems can be based on different Radio Access Technologies (RATs). Additionally, given the wide range of scenarios targeted by the QoSMOS system, different RATs with different characteristics (long/short range, ad-hoc/infrastructure, etc.) have to be considered. Thus, the handling of several RATs has to be part of the architecture. The objective is to facilitate the exchange of control data between the QoSMOS architecture building blocks (for example the building blocks on the terminal side and those on the network side) whatever the RAT used on lower layers. Another objective is to manage the measurement reports in a RAT-independent manner: a building block shall be able to cope with different RATs and get measurement reports from them without having to manage the RAT specificities (i.e. the RAT specificities shall be abstracted to the QoSMOS architecture building blocks).

Req. ID:	A.mratsup
Title:	Multiple RAT support
Text:	*The QoSMOS architecture shall support several RATs and be able to select the most pertinent one among these RATs*
Related requirements:	S.coex; P.traf; P.qos-iw; P.term; P.drate; P.lat; P.cov; A.ifintra; A.ifinter; A.ifext; A.mrat-iw;
Related QoSMOS WPs:	WP2: Interfaces WP5: Selection of RAT and the collection of information from different RATs through specific interface
Scenario constraints:	Same relevance for all scenarios
Notes:	

Req. ID:	A.mrat-iw
Title:	Multiple RAT interworking
Text:	*The QoSMOS architecture shall support the interworking between selected available Radio Access Technologies (RATs) and the mobility between those RATs*
Related requirements:	S.coex; P.qos-iw; P.term; P.hosupp; A.ifintra; A.ifinter; A.ifext; A.mratsup
Related QoSMOS WPs:	WP2: Interfaces and capabilities WP5: Vertical mobility handling; WP6: Sharing portfolio information
Scenario constraints:	Same relevance for all scenarios
Notes:	

8.2 Security

Statement: The security mechanisms shall ensure that a node can trust the control data (such as spectrum portfolio, measurement report, reconfiguration decision, etc.) received from another node: control data can be trusted if the source of the information is authenticated and that the information has not been modified on the way between the source and the destination (integrity protection).

Req. ID:	A.sec
Title:	Security
Text:	*The QoSMOS system shall ensure robust privacy security mechanisms as privacy implications arise, since the location of a user device is involved when accessing the database portfolio*
Related requirements:	B.userv; B.multiserv; A.reginfpol; A.geoloc
Related QoSMOS WPs:	WP5: Authentication at association WP6: Trusted relationships for database portfolio exchange between Geolocation database system and QoSMOS system.
Scenario constraints:	Same relevance for all scenarios
Notes:	

8.3 Flexibility

Statement: The uses cases targeted by the QoSMOS system vary from short-range network to long-range network and have different topologies (infrastructure-based, ad-hoc). This has an impact on the architecture especially on the distribution of the decision making / control (centralized versus decentralized approach). The use cases targeted by the QoSMOS system imply that there are differences.

Req. ID:	A.flex
Title:	Flexibility
Text:	*The QoSMOS system shall be flexible enough to comprise different architectures which can support a variety of use cases ranging from short-range ad-hoc network to long-range infrastructure network.*
Related requirements:	B.cost; B.userv; B.multiserv; S.freq; S.cch; P.traf; P.qmaintain; P.umob; P.term; P.hosupp; P.drate; P.lat; P.cov; A.scale;
Related QoSMOS WPs:	WP2: Different architectures to support the different use cases shall be taken into account using the reference model framework WP5: Efficiency and overhead of protocols and access methods;
Scenario constraints:	Same relevance for all scenarios
Notes:	Performance (P.) requirements do not change with QoSMOS realization (although some requirement will apply to some scenario but no to other, e.g., mobility), but the values attached to them will. A common channel may be realized in different ways depending on the realization of the QoSMOS system.

8.4 Scalability

Statement: Depending on the use cases, the number of mobile terminals can be low (small ad-hoc network) or high (large infrastructure-based network). The system shall be capable of adapting to these different requirements. This has an impact on the distribution of the decision making and on the dimensioning of the signalling.

Req. ID:	A.scale
Title:	Scalability
Text:	*The QoSMOS system shall be able to handle growing amounts of mobile terminals or have the ability to be enlarged to accommodate that growth*
Related requirements:	B.cost; A.flex;
Related QoSMOS WPs:	WP5: Robustness of CM-RM radio resource management; Dimensioning of control channel WP6: Robustness of Control channels to access Database portfolio
Scenario constraints:	Same relevance for all scenarios
Notes:	

9 Scenario constraints

This chapter is a summary of the scenarios' influence on how system requirements should be interpreted differently for QoSMOS deployments.

Table 9-1 Scenarios' influence on business, service and user requirements

Req. ID	Influence
B.cost – Total cost	Same relevance for all scenarios
B.trading – Spectrum trading	Same relevance for all scenarios
B.userv – End user services	Same relevance for all scenarios
B.multiserv – Wholesaling	Same relevance for all scenarios
B.term – Terminal types	Different terminal types are relevant in different scenarios and use cases

Table 9-2 Scenarios' influence on system operations requirements

Req. ID	Influence
S.freq – Frequency independence	All possible frequency bands are not relevant for all scenarios, thus QoSMOS deployments should support only the bands relevant for the scenario and region.
S.coex – Co-existence	Same relevance for all scenarios
S.ctxinfo – Context information collection	Same relevance for all scenarios
S.ctxresp – Context based response capability	Same relevance for all scenarios
S.intf – Interference avoid.	Same relevance for all scenarios
S.ulay – Underlay operation	This requirement might only be relevant for short range scenarios due to the limited transmitter power.
S.prot – Incumbent protection	Same relevance for all scenarios
S.sens – Sensing for inc. Prot.	Same relevance for all scenarios
S.geoloc – Geolocation accuracy	The method used for acquiring position info may differ between the scenarios.
S.pwr – Transmitter power	The current regulations in the 470-790 MHz band do not distinguish between deployment scenarios. In the future, different frequency bands accompanied by different transmitted power limits may be used in different scenarios.
S.rob – Robustness	Same relevance for all scenarios
S.cch – Common channel	Same relevance for all scenarios
S.mal – Malicious use	Same relevance for all scenarios

Table 9-3 Scenarios' influence on performance requirements

Req. ID	Influence
P.traf – Traffic classes	QoSMOS deployments in certain scenarios may be allowed to support only a subset of the total amount of traffic classes, dependent on the uses cases which are to be served.
P.qos-iw – QoS interworking	Same relevance for all scenarios
P.qmaintain – Maintaining QoS	Same relevance for all scenarios, however, the range of QoS classes may differ for QoSMOS deployments in the different scenarios
P.qpri – QoS priority	Same relevance for all scenarios
P.srvrestart – Service re-establishment	Same relevance for all scenarios
P.umob – User mobility	It is relevant for all scenarios; however, the actual degree of mobility will differ.
P.term – Terminal mobility	Different terminal mobility support is foreseen in the different scenarios. Support for handover due to physical mobility may not be applicable in all scenarios. This is most likely to be the case for the dynamic backhaul scenario.
P.hosupp – Handover support (physical mobility)	Support for handover due to physical mobility may not be applicable in all scenarios. This is most likely to be the case for the dynamic backhaul scenario.
P.chchg – Handover support (spectrum mobility)	Same relevance for all scenarios
P.spect – Spectrum utilization	The need for high spectrum efficiency is not equal in all scenarios. In the cellular extension and cognitive femtocell scenarios the spectrum efficiency should approach the current state-of-the-art, but in others, e.g. ad hoc networks this requirement may be more relaxed. In an emergency ad hoc network robust links will be important, and this usually means larger overhead in the physical layer protocol.
P.oob – Out-of-band radiation	Same relevance for all scenarios
P.drate – Data rates	The data rates to be provided will vary depending on the use case that is serviced. The QoSMOS transceiver implementation cannot be one-size-fits-all, but has to be according to the deployment scenario. The short range scenarios (cognitive ad hoc and femto-cell) will put higher demands on the data rate than cellular extension and direct terminal-to-terminal. The same will probably be for the rural broadband.
P.lat – Latency	Different QoSMOS scenarios will require different latency figures, depending on the use cases they serve
P.srxsens – Sens. Rx sensitivity	The required sensitivity will vary between different scenarios.

Req. ID	Influence
P.crxsens – Comm. Rx sensitivity	The required sensitivity will vary between different scenarios.
P.cov - Coverage	The expected coverage differs between scenarios from a few meters in the case of ad hoc networks and femto-cell deployments up to tens of kilometres for rural broadband.

Table 9-4 Scenarios' influence on architecture and complexity requirements

Req. ID	Influence
A.ifintra – Same QoSMOS op	Same relevance for all scenarios
A.ifinter – Other QoSMOS op	Same relevance for all scenarios
A.ifext – Other opp. Sys	Same relevance for all scenarios
A.reginfpol – Regulatory info	Same relevance for all scenarios
A.geoloc – Geolocation database	Same relevance for all scenarios
A.mratsup – Multi RAT supp.	Same relevance for all scenarios
A.mrat-iw – Multi RAT IW	Same relevance for all scenarios
A.sec – Security	Same relevance for all scenarios
A.flex – Flexibility	Same relevance for all scenarios
A.scale - Scalability	Same relevance for all scenarios

10 Conclusions and further work

In this report, the system requirements of the QoSMOS system have been identified and defined. The main goal is to ensure that the QoSMOS system is designed to be competitive in all respects. In the market place it will be compared to existing and conventional wireless technologies, therefore it needs to have a matching performance in economical as well as in technical aspects. It has also been important to ensure that only relevant requirements are included.

The QoSMOS system shall be designed to be frequency agnostic. This means that the QoSMOS system as a whole shall be able to support any frequency band which is made available for opportunistic access. However, the implementation and deployment of QoSMOS will be limited to supporting defined frequency bands, dependent on the local or regional regulatory situation. Currently supported bands are limited to the so-called TV Whitespace in the UHF band from 470-790 MHz, but other bands are identified and discussed. To support the evolution of QoSMOS, a frequency band designation system is defined. In the future, it opens for QoSMOS to support differently regulated bands:

- Opportunistic access in the presence of licensed (incumbent) users
- Shared access
- Planned access

It is expected that more frequency bands will be available for opportunistic or dynamic frequency access in the future, like e.g. bands which today are exclusive to military use.

The QoSMOS requirements have been sorted in four categories, but it is important to stress that these categories are not independent of each other. We see that e.g. aspects like co-existence and mobility are covered across them.

Business, service and user related requirements address parameters and functions which shall ensure that the QoSMOS system will be attractive for actors and stakeholders. Business requirements are motivated by the need for QoSMOS to be competitive in the wireless industry. The most important side of this is to ensure that the system is designed to be cost-effective in all phases: development, production, operation and use. Service related requirements include both end-user aspects and wholesale service provisioning. The user aspects are also addressed by including support for different terminal types.

System operation related requirements are mostly related to regulatory compliance. This is a key category for any telecom system, not only wireless and not only cognitive. However, it is of crucial importance that future cognitive radio systems to comply with emerging and changing regulatory regimes. This comprises compliance with specific technical requirements as well as the ability to take up new regulatory paradigms. Regulations for CR are to a great extent about co-existence in an increasingly crowded wireless landscape. Therefore we have also included environmental aspects. This is about ensuring that QoSMOS also has the necessary functionality to be an efficient system in terms of equipment power consumption and low emissions.

Performance related requirements constitute technical parameters, including QoS, mobility and physical layer performance, and how QoSMOS should be beyond state-of-the-art. The latest developments in wireless system performance from 3GPP and IEEE have been used to define the requirements. The QoSMOS system performance will be compared to existing system, and will together with the economy aspects be the basis for the success in the market. Performance is defined in data rates, spectrum efficiency and latency, to mention some.

Architecture and complexity related requirements address the network aspects of QoSMOS. Two main goals have been addressed: the need for reduced complexity and the necessary functional flexibility. There is a need for sufficient and relevant interfaces to ensure co-existence and cooperation with other QoSMOS implementations, other CR-systems and also legacy radio access technologies. Flexibility is necessary to ensure support of the variety of scenarios and use cases depicted for QoSMOS. Scalability is necessary to support large networks comprising many terminals and base stations.

The QoSMOS requirements have been defined to be valid across any operational frequency, deployment scenario and regulatory rulings. QoSMOS realization and deployment will meet constraints related to the different scenarios, and these have been identified and also summarized. The most important differences are found to be on mobility, bandwidth needs, power limitations and interference handling.

The requirements together with the scenarios produced will now be used as a reference to specify and design the QoSMOS system with its entities and functionalities:

- WP1: Together with the scenarios to perform business case definitions and analysis and defining spectrum micro-trading metrics and spectrum sharing models
- WP2: Define the system specifications, including metrics and quantified goals. Together with the scenarios evaluate the system and produce deployment guidelines
- WP3: Define and assess the performance and functionality of the sensing engine
- WP4: Define the metrics for assessing physical layer performance and flexibility
- WP5: Derive the algorithms, strategies and mechanisms needed to support QoS and mobility according to the requirements
- WP6: Refine the specific requirements related to the spectrum management framework

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Appendix A. Tables of requirements and their inter-relations

Table 11-1 Dependencies between requirements mapped from business, service and user related requirements

Category B: Business, service and user related requirements	B.cost	B.trading	B.userv	B.multiserv	B.term	S.freq	S.coex	S.ctxinfo	S.ctxresp	S.intf	S.ulay	S.prot	S.sens	S.geoloc	S.pwr	S.rob	S.cch	S.mal	P.traf	P.qos-iw	P.qmaintain	P.qpri	P.srvrestart	P.umob	P.term	P.hosupp	P.chchg	P.spect	P.ob	P.drate	P.lat	P.srxsens	P.crxsens	P.cov	A.ifintra	A.ifinter	A.ifext	A.reginfpol	A.geoloc	A.mratsup	A.mrat-iw	A.sec	A.flex	A.scale
B.cost – Total cost																																											X	X
B.trading – Spectrum trading						X																																X						
B.userv – End user services				X															X	X	X	X	X	X	X					X	X			X								X	X	
B.multiserv – Wholesaling			X																X	X	X	X																				X	X	
B.term – Terminal types								X	X															X	X																			

Table 11-2 Dependencies between requirements mapped from system operation related requirements

Category S: **System operation related requirements**	B.cost	B.trading	B.userv	B.multiserv	B.term	S.freq	S.coex	S.ctxinfo	S.ctxresp	S.intf	S.ulay	S.prot	S.sens	S.geoloc	S.pwr	S.rob	S.cch	S.mal
S.freq – Frequency ind.		X																
S.coex – Co-existence										X		X		X				
S.ctxinfo – Context info collection					X				X				X	X				
S.ctxresp – Context based resp.					X			X										
S.intf – Interference avoid.							X				X	X			X			
S.ulay – Underlay operation										X					X			
S.prot – Incumbent protection							X			X			X	X	X			
S.sens – Sensing for inc. Prot.								X				X						
S.geoloc – Geolocation accuracy							X	X				X						
S.pwr – Transmitter power										X	X	X						
S.rob – Robustness																		X
S.cch – Common channel																		
S.mal – Malicious use																X		

Category S: **System operation related requirements**	P.traf	P.qos-iw	P.qmaintain	P.qpri	P.srvrestart	P.umob	P.term	P.hosupp	P.chchg	P.spect	P.oob	P.drate	P.lat	P.srxsens	P.crxsens	P.cov
S.freq – Frequency ind.										X	X	X				
S.coex – Co-existence																
S.ctxinfo – Context info collection			X											X		
S.ctxresp – Context based resp.			X													
S.intf – Interference avoid.															X	
S.ulay – Underlay operation																
S.prot – Incumbent protection									X	X	X	X				
S.sens – Sensing for inc. Prot.														X		
S.geoloc – Geolocation accuracy																
S.pwr – Transmitter power															X	X
S.rob – Robustness																
S.cch – Common channel																
S.mal – Malicious use																

Category S: **System operation related requirements**	A.ifintra	A.ifinter	A.ifext	A.reginfpol	A.geoloc	A.mratsup	A.mrat-iw	A.sec	A.flex	A.scale
S.freq – Frequency ind.				X					X	
S.coex – Co-existence	X	X	X	X	X	X	X			
S.ctxinfo – Context info collection	X	X	X	X	X					
S.ctxresp – Context based resp.	X	X	X	X						
S.intf – Interference avoid.				X						
S.ulay – Underlay operation				X						
S.prot – Incumbent protection				X	X					
S.sens – Sensing for inc. Prot.				X						
S.geoloc – Geolocation accuracy				X	X					
S.pwr – Transmitter power				X						
S.rob – Robustness										
S.cch – Common channel									X	
S.mal – Malicious use										

Table 11-3 Dependencies between requirements mapped from performance related requirements

Category P: Performance related requirements	B.cost	B.trading	B.userv	B.multiserv	B.term	S.freq	S.coex	S.ctxinfo	S.ctxresp	S.intf	S.ulay	S.prot	S.sens	S.geoloc	S.pwr	S.rob	S.cch	S.mal
P.traf – Traffic classes			X	X														
P.qos-iw – QoS interworking			X	X														
P.qmaintain – Maintaining QoS			X	X				X	X									
P.qpri – QoS priority			X	X														
P.srvrestart – Service re-est.			X															
P.umob – User mobility			X		X													
P.term – Terminal mobility			X		X													
P.hosupp – Handover support (p)																		
P.chchg – Handover support (f)												X						
P.spect – Spectrum utilization						X						X						
P.oob – Out-of-band radiation						X						X						
P.drate – Data rates			X			X						X						
P.lat – Latency			X															
P.srxsens – Sens. Rx sensitivity								X					X					
P.crxsens – Comm. Rx sensitivity										X					X			
P.cov - Coverage			X												X			

Category P: Performance related requirements	P.traf	P.qos-iw	P.qmaintain	P.qpri	P.srvrestart	P.umob	P.term	P.hosupp	P.chchg	P.spect	P.oob	P.drate	P.lat	P.srxsens	P.crxsens	P.cov
P.traf – Traffic classes		X	X	X									X			
P.qos-iw – QoS interworking	X		X	X	X	X						X	X			
P.qmaintain – Maintaining QoS	X	X		X	X		X	X	X							
P.qpri – QoS priority	X	X	X		X				X							
P.srvrestart – Service re-est.		X	X	X					X							
P.umob – User mobility		X						X								
P.term – Terminal mobility			X					X	X			X				
P.hosupp – Handover support (p)			X			X	X									
P.chchg – Handover support (f)			X	X	X		X									
P.spect – Spectrum utilization											X	X				
P.oob – Out-of-band radiation										X						
P.drate – Data rates		X					X			X						
P.lat – Latency	X	X														
P.srxsens – Sens. Rx sensitivity																
P.crxsens – Comm. Rx sensitivity																X
P.cov - Coverage															X	

Category P: Performance related requirements	A.ifintra	A.ifinter	A.ifext	A.reginfpol	A.geoloc	A.mratsup	A.mrat-iw	A.sec	A.flex	A.scale
P.traf – Traffic classes						X			X	
P.qos-iw – QoS interworking	X	X	X			X	X			
P.qmaintain – Maintaining QoS	X	X	X						X	
P.qpri – QoS priority										
P.srvrestart – Service re-est.										
P.umob – User mobility									X	
P.term – Terminal mobility						X	X		X	
P.hosupp – Handover support (p)							X		X	
P.chchg – Handover support (f)										
P.spect – Spectrum utilization										
P.oob – Out-of-band radiation										
P.drate – Data rates						X			X	
P.lat – Latency						X			X	
P.srxsens – Sens. Rx sensitivity										
P.crxsens – Comm. Rx sensitivity										
P.cov - Coverage						X			X	

Table 11-4 Dependencies between requirements mapped from architecture and complexity related requirements

Category A: Architecture and complexity related requirements	B.cost	B.trading	B.userv	B.multiserv	B.term	S.freq	S.coex	S.ctxinfo	S.ctxresp	S.intf	S.ulay	S.prot	S.sens	S.geoloc	S.pwr	S.rob	S.cch	S.mal	P.traf	P.qos-iw	P.qmaintain	P.qpri	P.srvrestart	P.umob	P.term	P.hosupp	P.chchg	P.spect	P.oob	P.drate	P.lat	P.srxsens	P.crxsens	P.cov	A.ifintra	A.ifinter	A.ifext	A.reginfpol	A.geoloc	A.mratsup	A.mrat-iw	A.sec	A.flex	A.scale
A.ifintra – Same QoSMOS op							X	X	X											X	X															X	X			X	X			
A.ifinter – Other QoSMOS op							X	X	X											X	X														X		X			X	X			
A.ifext – Other opp. Sys							X	X	X											X	X														X	X				X	X			
A.reginfpol – Regulatory info		X				X	X	X	X	X	X	X	X	X	X																								X			X		
A.geoloc – Geoloc. database								X				X		X																								X				X		
A.mratsup – Multi RAT supp.							X												X	X					X					X	X			X	X	X	X				X			
A.mrat-iw – Multi RAT IW							X													X					X	X									X	X	X			X				
A.sec – Security			X	X																																		X	X					
A.flex – Flexibility	X		X	X		X											X		X		X			X	X	X				X	X			X										X
A.scale - Scalability	X																																										X	

Appendix B. Sensing approach to incumbent detection in the 470-790 MHz band

Limiting the impact of interference for incumbents comprises techniques such as interference avoidance, mitigation and control. It can be narrowed down into more technical terms as:

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

Regarding the first issue, three options are considered by regulators. The first one relies on the fact that an opportunistic radio is able to directly 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 opportunistic sensor can detect the presence of the incumbent when it is far out of the coverage zone of the incumbent system. Actually, the sensitivity requirement is set to put the opportunistic transceiver at a distance corresponding to the path loss of the incumbent plus the path loss of the opportunistic transmitter plus a certain margin also called 'no talk area'. This is illustrated in Figure 11-1.

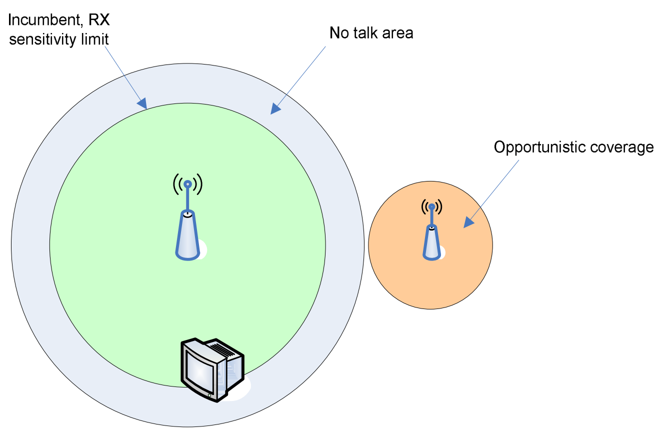

Figure 11-1 Sensing approach to incumbent detection

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. Then, the sensitivity requirements have to be considered together with the transmitted power allowed.

USA:

In [3] 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.

On Sept. 23rd 2010, the FCC has published a second Memorandum [5] that allows TVWS communication for the specific application of so called "super Wi-Fi hot spot". For this application, spectrum sensing requirements are withdrawn and detection of incumbents is achieved through geolocation 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.

Just recently, on Nov. 30th 2010, the FCC has issued two new documents. The first is a "Notice of Proposed Rulemaking" (FCC doc 10-197) [13] on expanding the opportunities for radio experimentation and market trials. This proposal addresses the possible relaxation of current rulings to ease experiments and trials. The second is a "Notice of Inquiry" on promoting more efficient use of spectrum through dynamic spectrum use technologies (FCC doc 10-198) [14] in which both extended use of real-time databases (article 48) and the use of country-wide real-time spectrum monitoring networks (article 50) is addressed.

United Kingdom:

In the UK, the Ofcom started Digital Dividend Reviews from 2005 on, 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 [4]. 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.

Recently, due to the difficulty of manufacturers to develop high sensitivity sensors at low cost, and in order to make this market emerge in a near future though, the Ofcom seems to go towards a geolocation only protection mechanism [15]. However, it should be noted that [15] is not an official regulatory document, but a presentation on Ofcom's vision at a workshop.

Europe:

In Europe, the project team SE43, within the Electronic Communications Committee (ECC) of CEPT is tasked with defining the technical and operational requirements of operating in the TV white spaces. They are working on a first report which will be delivered in May 2011 and which is already available on the CEPT webpage as a draft [17] [6]. This work is based on studies of national regulators in Europe. Several scenarios are investigated in [6] taking into account a range of potential DTT receiver configurations and DTT planning scenarios. The detection thresholds are in the range of -91dBm to -165dBm. This leads the CEPT ECC to conclude that sensing only is not a preferred solution to protect the broadcast service. This means that there is a need to employ also geo-location with access to database (see hereunder). In cases where other approaches such as geo-location in connection with access to database can provide sufficient protection to the broadcast service, sensing should not be a requirement. The potential benefit of using sensing in addition to the geo-location database needs to be further considered. To protect emerging DTT and PMSE systems, sensing algorithm would require continuous developments, which may raise legacy issues.

Appendix C. Approaches to emission limits in the 470-790 MHz band

Two main approaches are considered to define the emission limits.

- **Location specific maximum output power**: the allowed output power can be determined for each location, frequency and device type/class within the database. Such an approach requires the use of geo-location,
- **Fixed maximum output power**: There may be a few device types (such as portable and fixed) for which the key main characteristics are predefined, and certain fixed output power limits are allowed for them to be used outside the protected areas. The limits may be different for use of adjacent channels and for other channels.

USA:

The FCC considers the fixed maximum output power strategy; however the FCC distinguishes 2 device profiles, either fixed or portable and sets power levels and detection capability accordingly:

- **Fixed cognitive devices** operate from a known and fixed location can operate with up to 4 W EIRP. They are required to have a geolocation capability and the capability to retrieve a list of available channels from an authorized database. They can only operate on channels that are not adjacent to an incumbent TV signal in any channel between 2 and 51 except 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 geolocation capability or access to a database But should be able to communicate with and operate on channels identified by Mode II devices, which like fixed devices, must have geolocation database access.

United Kingdom:

The Ofcom considers the fixed maximum output power strategy also. Unlike the FCC, the Ofcom does not set maximum power depending on the type of device. It recommends that in order 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.

Europe:

The ECC, in its draft document [6], suggests using location specific maximum output power approach.