# REQUIREMENTS FOR A CR-SYSTEM – CHALLENGES COMPARED TO CONVENTIONAL WIRELESS TECHNOLOGY

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## ABSTRACT

Cognitive Radio (CR) technology is a promising enabler towards a more efficient and dynamic use of the frequency spectrum. The challenges related to using the vacant frequencies in an opportunistic manner put extra constraints on the system if it is going to provide reliable services to the end user. When, in addition, we want a system to provide managed quality of service (QoS) and mobility, the challenges are even more demanding. There are two major challenges for cognitive radio systems based on opportunistic spectrum access: the need to keep track of the spectrum; and the aim of providing managed QoS and mobility. Both these are external constraints generally not present for licensed wireless operation and they call for additional functionality and flexibility in the system as well as the need for additional interfaces to handle the new information. The EU-project QoSMOS has addressed this in defining the overall requirements for the system and we show how these responds to the challenges.

## 1. INTRODUCTION

Since Cognitive Radio (CR) was "defined" in 2000 by Joseph Mitola III [1], there has been extensive research on its application and on the related enabling techniques. One of the most promising applications of cognitive methods is opportunistic spectrum access.

With opportunistic spectrum access (OSA) the wireless nodes try to exploit spectrum resources owned by an incumbent, without causing detrimental interference. This approach requires a great deal of capabilities from the opportunistic radio system. In this paper the discussion is mostly concerned with opportunistic access based on a spectrum sharing model (see Sect. 6.3) usually called "interweave" [2]. This mode means that the system seeks to exploit vacant frequency resource in time and space. Opportunistic access can also be based on underlay methods, like e.g. Ultra Wideband (UWB)), and overlay mode, the latter implying special coding techniques in order to "protect" the incumbents "right-of-way" [3].

Opportunistic access also includes shared spectrum access, i.e. that several operators or users share the same spectrum on equal terms. This is the basic rule for Wi-Fi and Bluetooth systems, for example, in the ISM-band (2.4 GHz). It is easy to understand that this mode also must be a part of the conditions under which an opportunistic system must operate, since several OSA-based systems may compete for the same resource.

In the QoSMOS-project [4], this approach is researched with the aim of finding the solutions necessary to provide a managed Quality of Service (QoS) and mobility in such a setting.

Defining requirements for an opportunistic wireless system can be compared to aiming and shooting at moving targets. The aforementioned needed spectrum agility is one reason for this, another one is the regulatory situation. Regulations for OSA are in their infancy, and this also makes it difficult to know which functions and attributes are needed. The flexibility to comply with evolving regulations is in fact a specific requirement for an effective CR system.

In this paper we will highlight and discuss the extra challenges which stems out of the two above mentioned factors. We start with discussion on reliability, and then identify the challenges. We will present the QoSMOS approach to defining requirements and how they respond these challenges.

## 2. RELIABLE SERVICES OVER UNRELIABLE RESOURCES

Unreliable physical resources is a general challenge for all wireless systems, however opportunistic spectrum access adds an additional factor of unreliability to this, namely that the operator of the system cannot plan the frequency use a long time ahead. Planning and decision must be almost instantaneous when service is requested. Opportunistic use also implies that service interruptions caused by the appearance of an incumbent pre-empting the used resource have much bigger impact on the QoS than the changes in propagation conditions that licensed systems, for example, suffer.

A CR system operates in an environment very different from those using dedicated spectrum portions, whether they are dedicated to the system in question, such as licensed users, or shared with competing users, like is the case with systems operating in ISM bands. This indeed generates a set of specific requirements on the transceiver.

Moreover, a successful CR system should exploit the position of legacy systems. These two facts bring challenges to the CR system design, which need both to incorporate new features and to be compatible with legacy systems' architectures.

Necessary requirements for a CR system include basically the same as for conventional systems. Additionally, the system must be capable of switching between different operating frequencies in a rapid and flexible fashion that places great demand on functions like power control and handover. It shall also offer the opportunity to deliberately exploit the differences in the characteristics of the available spectrum portions. For example, differences in propagation and wall penetration can be exploited depending on the application or, more generally, simply be taken into account.

Spectrum resources not used in time and space by an incumbent, referred to as whitespace, will likely be used by more than a single opportunistic user. Therefore, measures for coexistence among the latter should be taken. The context in which an opportunistic system operates therefore creates the need for functions and interfaces to ensure co-existence with the incumbent wireless systems as well as other opportunistic systems.

## 3. DIFFERENCES IN CONSTRAINTS

As mentioned in the introduction, there are two factors which make requirements definition an exercise similar to aiming and shooting at a moving target.

A still immature regulatory situation makes it difficult to know the constraints on opportunistic spectrum use. Regulators have been starting to work out how the operating conditions for opportunistic access might become. In the USA, FCC has since 2008 allowed opportunistic access in the so-called "TV Whitespace" (TVWS), basically the UHF-band 470-790 MHz, which is globally regulated for terrestrial television. Among European regulators, the most forward-leaning regulator is Ofcom in the UK, which also is working on the issue. In Europe, important decisions which can open up for such use will be taken by CEPT, which already has issued a technical report on requirements for opportunistic access in the TVWS [5].

The main issues which are treated by the regulatory authorities are centered on one goal, namely the protection of incumbents' services. This manifests itself in requirements on transmitter power levels, interference avoidance and channel evacuation for the opportunistic nodes.

This leads to the second difference. The general unpredictability of the spectrum availability, even with known constraints creates a need for the opportunistic system to keep track of the incumbent use.

## 4. CHALLENGE 1: KEEPING TRACK OF SPECTRUM

The main challenges of operating in an opportunistic manner, then stems from the main constraint that other users of the same spectrum should not be disturbed or interrupted An opportunistic system must be able co-exist with two kinds of concurrent users of the same spectrum:

1. Incumbent users have the "right-of-way" in exploiting own spectrum and opportunistic users must correspondingly avoid interference or disturbance to them.
2. Other opportunistic users have the same "right" of shared access to the same spectrum. All opportunistic users should effectively co-exist.

In other words, the user of spectrum in an opportunistic manner faces with coexistence at two different levels but the accepted level of disturbance may differ.

This translates into the need for keeping track of spectrum resources quite differently than is the case of licensed systems, in which the owner has control of the details regarding channels and frequencies. It influences the following capabilities of the system:

*Radio resource management (RRM)* now also includes spectrum management on a broader scale. In conventional cellular technology, RRM is confined to optimizing resource usage on the set of defined channels for the specific system (UMTS, LTE, ...). Transmit power control and scheduling; for example, depend also on constraints external to the operated network.

*Mobility management (MM)* now includes a new kind of mobility in addition to the physical, which we call spectrum mobility, as explained below. Mobility support as provided by current cellular systems deals with change of point of attachment as a terminal moves across coverage areas, i.e., in presence of physical mobility. As an opportunistic user may need to vacate a pre-empted resource, service continuity implies moving that user to another spectrum resource. In other words, this reflects in spectrum mobility mechanisms. The corresponding supporting measures share similarities, which can be exploited in the design.

In addition, keeping track of the available spectrum also identifies a need for new capabilities not appearing in licensed systems. Tracking available spectrum implies the knowledge about the usage those spectrum portions. This can be achieved in basically two ways. One uses *a priori* knowledge of occupation at a given location and time of a given spectrum portion as anticipated for example by its incumbent. This knowledge is conveyed by an authorized database. The other way is to exploit *a posteriori* knowledge of users by using spectrum sensing. Both methods open up a set of requirements on the CR system.

## 5. CHALLENGE 2: PROVIDING QOS AND MOBILITY WHEN ACCESS IS OPPORTUNISTIC

The QoSMOS project's aim at demonstrating how to provide managed QoS and mobility support when exploiting opportunistic access, i.e., with possibly interrupted available resources, adds an extra challenge. Providing simultaneous QoS and mobility is in itself a challenge well known to cellular operators. For example it is usual to constrain a single user's data rate in order to provide a more fair treatment of all users. Mobile environment impairs wireless link capabilities introducing the need for tradeoffs with QoS. On the other hand, the possible unavailability of spectrum resources due to both temporal variations in the incumbent activity and in the spatial variations due to mobility further reduces the degree of freedom of spectrum access.

Because planning resource usage in the space-frequency domain for opportunistic systems is difficult, QoS guarantees with moving users are really challenging. This is why QoS requirements, and service level agreements (SLAs) correspondingly, need to be rethought when opportunistic spectrum user comes in the picture. It is worth noting that SLAs for an opportunistic (or partly opportunistic) system may integrate the above trade-offs in terms of users' expectation.

Consequences of this are that the system must have an ability to quickly relocate users in the spectrum domain. It also opens up a research topic on whether vacant resources can be predicted.

## 6. THE QOSMOS APPROACH TO REQUIREMENTS SPECIFICATION

Setting up requirements for a system studied under a research project is, especially in the beginning, not exactly the same as defining requirements for standards specifications. Requirements identified and set for the QoSMOS system will to a larger degree act like goals. From the requirements, system specifications are defined based on the research results.

### 6.1. 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 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 the operating frequency band and regulations.

Typical frequency independent parts of the QoSMOS system are:

- The system architecture
- The spectrum management framework

QoS and mobility solutions will contains issues both of frequency independence and dependence.

The frequency dependent parts of the QoSMOS system are:

- The radio environment mapping and sensing
- The physical layer architecture

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

The UHF TV band (470 – 790 MHz) 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) having a better spectral efficiency than its analogue counterpart.

The regulatory situation concerning TVWS is that currently in USA, this spectrum is made available; while in Europe, as seen above, consultations are being carried out by Ofcom in the UK and technical requirements are produced by CEPT. Some other prospective bands are also studied in the project.

### 6.2. Requirement categories

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. They are:

*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)

*System operation related requirements:*

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

*Performance related requirements:*

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

*Architecture and complexity related requirements:*

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

The business user related requirements are not within the scope of this paper; however, it is of course a challenge to ensure the competitiveness in the wireless market. Providing technically sound and efficient solutions is a pre-requisite for this.

### 6.3. System operations must comply with regulations

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 must therefore be interpreted in the light of identified frequency bands and regulatory situation.

*Co-existence* is mandatory towards incumbent users of the spectrum. All QoSMOS systems deployed in an area must have the capability to cooperate for sharing the spectrum resources efficiently.

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, for example.

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.

Different spectrum sharing models can be used and they will put different constraints on the system. *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. 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. Currently, only FCC (USA) has defined a power spectral density limit of -41.3 dBm/MHz for underlay communications using UWB techniques for frequencies between 3.5 and 10.5 GHz [6]. Opportunistic systems must limit the transmit power in order to comply with the constraints on interference at possible incumbent receivers.

Another sharing model which is of higher interest for cognitive radio is called *interweave operation*. This means dynamic exploitation of spatial and temporal spectral opportunities in a non-interfering manner [2]. It basically translates into allowing opportunistic transmission only when and where incumbent signal is absent (frequency, time and location). This is the sharing model which forms the basis for the studies in the QoSMOS project.

A required property of an opportunistic communication system operating in white spaces is the ability to avoid detrimental effects on transmissions of the incumbent user. *Interference avoidance* is then a common requirement mostly addressing *incumbent protection*. It should also be able to detect the presence of other opportunistic users thus potentially reducing the impact of destructive interference of coexisting communication systems. Possible means for that, alternative or complementary, are database and spectrum sensing. Regulatory authorities may put demands on the use of those.

Then, the fact that the opportunistic system needs to know where and when the incumbents are present turns into two main functional requirements:

1. 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.
2. When the opportunistic transmission is set: tracking the potential appearance of an incumbent signal and escape from the band whenever this situation occurs.

CEPT [5] 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:

- Broadcasting service (BS) in the band 470-790 MHz;
- Program Making and Special Event (PMSE) services in the band 470-790 MHz;

- 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 the bands adjacent to the band 470-790 MHz

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. One possible method is to detect the presence of incumbents by *sensing*. For the current situation in the TVWS this is not mandatory. 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 use at that place. 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. The accuracy required for geolocation systems in the USA, the UK and Europe in the 470-790MHz band is given in Table 1.

Table 1 Geolocation accuracy requirements for incumbent protection in the 470 – 790 MHz band

| FCC [7] [8] | Ofcom [9] | CEPT [5] |
|---|---|---|
| 50 m | 100 m | Not yet specified |

Another part of the incumbent protection strategy is to adapt the output power in order to limit unnecessary emissions. Table 2 lists the maximum allowed power limits defined by FCC, Ofcom and CEPT. Opportunistic devices could be able to adapt the transmitter power if regulations change, or if it is intended for use in different regions.

Table 2 Maximum power allowed in the 470 – 790 MHz band for cognitive radios

| | FCC [7] [8] | Ofcom [9] | CEPT [5] |
|---|---|---|---|
| **Tx power (fixed) EIRP** | 4 W | 100 mW | Local specific |
| **Tx power (portable) EIRP** | 100 mW | 100 mW | Local specific |
| **Tx power in adjacent bands to DTT** | 40 mW | 20 mW | Local specific |
| **Out-of-band radiation** | -55 dBm under the in-band level | -55 dBm under the in-band level | |

A cognitive communication system must be able to select the operating channels among a set of channels and may therefore need to move out from a highly disturbed or unusable resource. A method for enabling this kind of network coordination is to provide a *robust logical control channel* for network coordination. This could be a dedicated physical channel or non-intrusive communication methods, such as underlay spectrum sharing with very low transmit power

### 6.4. System performance

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. System performance includes both economy and technical performance. Technical performance can e.g. be traded off for low price. User expectation is then a yardstick which should lie behind most performance requirements.

One of the pillars of QoSMOS is the ability of *managing quality of service*. 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. The detailed requirements for QoS are defined in [10]. They have been taken as base for the consolidated requirements in this section.

*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. 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. The QoSMOS system must be able to perform the necessary prioritizing of the traffic coming from different users. 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. 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. Managing QoS means that the system must support the differentiation between traffic classes. This will ensure that the QoSMOS system contains the necessary technical solutions to provide managed QoS with different traffic classes.

*Interworking with other radio access technologies* (RAT) 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. Different systems have different definitions of QoS classes. It is therefore necessary for QoSMOS to define mappings and possible enhancements to some of 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.

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. Detailed requirements for mobility handling are defined in [10]. In QoSMOS, 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.

The QoSMOS system shall be able to support both mobile users and mobile terminals. *User mobility* addresses the basic mobility handling functionality needed to provide sufficient service continuity for the end-user. *Terminal mobility* implies that 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. 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 also results in a change in radio reception quality due to changes in the link budget. Fast mobility and achievable throughput or data rate are contradictory requirements and there is a trade-off between a high throughput and high mobility. There will not be need for the same mobility in all scenarios.

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

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. Another example is the need for optimizing spectrum usage due to changes in offered traffic.

The demand for increased throughput and data rates within given bandwidths requires efficient *spectrum utilization*. This includes both spectrum efficiency and *out-of-band radiation*.

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.

The out of band radiation is an important yardstick 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 system. For this purpose, various pulse shaping filters, e.g. root-raised cosine, can be used in the transceiver. OFDM system, although being extremely flexible, has a high adjacent channel leakage and will cause serious interference to the legacy users. 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.

The QoSMOS system will be designed to operate in very different and varied scenarios [11]. The indoor/outdoor, short/long range use cases have different demands for *data rates.* The data rates to be provided will vary depending on the use case that is served. The achievable data rates are tightly related to both transmitter power and available spectrum and corresponding spectrum efficiency. The physical layer and its radio resource management must be flexible enough to support high data rates when sufficient physical bandwidth resources are present.

Services and applications like video streaming, call transfer with fast handover, 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, thereby impacting the QoS of conversational and streaming traffic while an overall delay in packet transmission will severely impact the end-to-end latency for voice and video services. As an example, latency requirements and performance for 3GPP LTE is 100 ms and 5 ms for the C-plane and U-plane, respectively. 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.

*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 defined 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. Both need to have high sensitivity; however the requirements for these two blocks have different motivations. For the sensing receiver, the required sensing performance may also be achieved by combining measurements from several sensors and improved sensing algorithms. The communication receiver's performance is guided by the need to obtain as good a link budget as possible. This is also correlated to the requirement on reducing interference by minimizing the field strength, and will often be quantified in conformance specifications as part of standards.

Different scenarios and use cases will represent different *coverage and ranges.* The QoSMOS system should handle different scenarios and use cases. 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 context and environment. This could e.g. stem from changes in the incumbent use and also the entry of other CR systems within the coverage area.

### 6.5. A flexible and scalable architecture

The architecture requirements are, by definition, the requirements identifying additional constraints on top of the system and functional requirements for the definition of the QoSMOS architecture. 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. To support the requirements on co-existence, interference avoidance and incumbent protection, there is a need to exchange information within the system and between systems. Therefore, the necessary interfaces must be in place to support this.

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

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

Functionalities needed for this requirement are also implied by requirements belonging to incumbent protection and associated to similar features.

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.

As described in section 6.3, a *geolocation database* shall be accessible to the QoSMOS system. This should be via an interface defined in the QoSMOS architecture. Especially, an interface between some of the QoSMOS architecture building blocks and a white space database shall exist as well as the appropriate interfaces between the architecture building blocks to ensure the spreading of the white space database data across the architecture.

The QoSMOS systems can be based on *different 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. There are two objectives for this:

- 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.
- 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 particularities (i.e. the RAT specialities shall be abstracted to the QoSMOS architecture building blocks).

In addition to the requirements on necessary interfaces, the QoSMOS system shall also be secure, flexible and scalable.

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).

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 calls for a *flexible architecture* especially on the distribution of the decision making and control (centralized versus decentralized approach) [12].

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 *scalable* and 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.

### 6.6. Responding to the challenges

QoSMOS project addresses the two major challenges highlighted in the previous sections, C1 and C2, identifying a number of requirements [13], see Table 3.

Table 3. Requirement groups responding to the CR-system-specific challenges

| Challenge: | C1 | C2 |
|---|---|---|
| Frequency flexibility | x | |
| Spectrum sensing; support and performance | x | |
| Geo-location; accuracy and interfaces | x | |
| Context information; collection and response | x | |
| Logical common channel | x | x |
| Regulation information | x | x |
| QoS interworking | x | x |
| User, terminal and spectrum mobility | | x |
| Physical and spectrum handover support | x | x |

## 7. CONCLUSIONS

In this paper, we have identified two major challenges for cognitive radio systems based on opportunistic spectrum access; the need to keep track of the spectrum; and the aim of providing managed QoS and mobility. Both these are external constraints generally not present for licensed wireless operation. Both these challenges call for additional functionality and flexibility in the system, like spectrum sensing, geo-location as well as the need for additional interfaces to handle the new information. We have shown how the EU-project QoSMOS has addressed this in defining the overall requirements for the system and how these responds to the challenges.

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