**WHITE PAPER**
**QUALITY OF SERVICE IN COGNITIVE RADIO SYSTEMS:**
**SYSTEM ARCHITECTURE OPTIONS**
**AND DETAILED FUNCTIONS**

**ABSTRACT**

In order to elaborate a framework for Cognitive Radio Systems making opportunistic use of radio spectrum like e.g. TV White Spaces, promising scenarios have to be identified first. The corresponding use cases must be studied in detail too. In the QoSMOS project three scenarios called ‘Cellular extension in White Spaces’, ‘Cognitive Femtocell’ and ‘Cognitive ad-hoc network’ have been selected as the most promising ones. The requirements which have to be fulfilled by the intrinsic system functions are then to be derived from the challenges encountered in the scenarios. These concern mostly stakeholders’ cost, system operation and performance as well as architecture and complexity. With the aim of a flexible architecture design for the QoSMOS system, the system functions needed to fulfil the requirements are illustrated in the overall system reference model elaborated. The combinations of centralised or distributed topologies for Resource Control with centralised, distributed or local topologies for Spectrum Sensing are used to characterise the realisation of the cognitive functions in the scenarios selected. System architecture options are presented for the various topologies’ combinations when mapped to the relevant network elements. Detailing the information flows over the network domains for ‘Spectrum Portfolio Management’, ‘Resource Control and Incumbent Protection’ as well as ‘Mobility Management’ shows the flexibility of the system architecture design achieved.
INTRODUCTION

The approach chosen by the QoSMOS project in terms of opportunistic use of spectrum by Cognitive Radio Systems (CRS) is driven by the support of QoS and Mobility Management. This implies that different network topologies for various scenarios have to be considered. Therefore especially high flexibility of the cognitive system architecture is needed in order to address the different use cases while keeping the scope of QoS demands by the opportunistic mobile users as well as the protection of the incumbents from interference.

The framework for CRS making opportunistic use of radio spectrum like e.g. TV White Spaces relies on the definition of realistic and promising scenarios and the corresponding use cases. Then the requirements which have to be fulfilled by dedicated system functions are derived from the challenges encountered. This approach is illustrated in the first chapter of this White Paper. With the aim of a flexible architecture design for the QoSMOS system, the various topologies applicable to the realisation of the cognitive functions in the scenarios selected are evaluated and an overall functional reference model is defined. The resulting architecture options reflect the mapping of the system functions to the topology domains as shown in the second chapter. The last chapter contains the detailed description of intrinsic cognitive system functions by means of the system architecture applied to the scenario considered and the information flows between the network elements in the relevant domains.

OPPORTUNISTIC SYSTEM WITH QoS AND MOBILITY MANAGEMENT

An opportunistic system supporting QoS and mobility faces challenges posed by its nature (like e.g. the use of whitespaces in a cognitive manner) as well as by the targeted scenarios and use cases. The system requirements to be fulfilled by the cognitive architecture are derived from these challenges and the functionalities needed are identified accordingly. This chapter describes scenarios, requirements and system functions as defined by the QoSMOS project.

Scenarios and Use Cases

The QoSMOS project has initially defined six scenarios to be studied as presented in [1]. Further investigations in the project led to the selection and refinement of three scenarios which have been evaluated as most commercially viable.

Cellular extension in whitespace

With a cellular extension in white space as depicted in Figure 1, mobile network operators (e.g. LTE-operators) will utilise white space spectrum in addition to their own licensed spectrum. The suitability of a spectrum band for this scenario depends on whether it is to be used for coverage or capacity enhancements. Examples of use cases for this scenario are:

- Capacity and coverage enhancements in LTE or LTE-Advanced networks
- Rural broadband involving the provision of wireless Internet connectivity to homes in rural locations through a base station.

The QoSMOS scenarios are considered to cover the most promising use cases in which cognitive radio will improve cost and performance.
The main benefits of using cognitive radio (CR) in this scenario are:

- **Better user experience due to more frequencies being available and potentially larger coverage.**
- **Increased operational bandwidths, resulting in capacity offload from the licensed band, improved link quality and more flexible services.**
- **The use of low frequencies increases range and therefore the transmit power can be kept lower. This reduces power consumption and reduces health risk concerns (especially for uplink transmissions).**
- **Due to their better penetration capabilities, the cognitive use of lower frequencies can be used to eliminate indoor coverage holes which are otherwise unavoidable at higher frequencies.**

### Cognitive femtocell

The femtocell scenario, depicted in Figure 2, describes a user situation with low mobility, but high demands on throughput and QoS. It may also be described as a “hot spot” scenario. Femtocells are always connected to an infrastructure. Both indoor and outdoor deployments are possible. Examples of use cases for this scenario are:

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

The main benefits of using cognitive radio for femtocells are mostly:
• Better interference control than current 3G/LTE femtocell technology which can improve capacity and coverage.
• Better user experience due to more frequencies being available and potentially larger coverage.
• Penetration loss due to building walls are an obstacle for macro networks, however for cognitive femtocells using higher frequency bands offers the advantage of better inter-cell isolation and more unused white space indoors.
• System design is easier if there is the possibility to patch up indoor coverage holes with cognitive femtocells.

Cognitive ad hoc network
The cognitive ad hoc network scenario, depicted in Figure 3, typically includes properties of high dynamics and different nodes and terminals. Ad hoc networks are typically limited in space and time. Examples of use cases for this scenario are:

• Emergency ad hoc networks with several actors (police, paramedics and fire fighters) who will typically have two needs: One is to communicate efficiently between one another; the other is to establish a connection to a rescue co-ordination centre.
• A network established for a business meeting to exchange documents and other information. Depending on the type of event, such a network may be partly pre-planned before the start.
• A network can be established to offload the regular network in case of an event with a very large crowd, such as a sporting event or a festival.

Figure 3: An emergency cognitive ad-hoc network

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

• The capacity can be increased to serve peak demands without the need for such bandwidth to be allocated during off-peak times.
• The use of low frequency bands is beneficial especially in emergency scenarios due the improved propagation through walls.
• If in case of an emergency or disaster where some of the permanent infrastructure goes offline, a cognitive ad hoc system can still provide reliable service.

Requirements and system functions
The requirements for the QoSMOS system address various targets, namely:

• QoSMOS shall be flexible with respect to operating frequencies.
• Different scenarios imply different specific requirements on the system.
• Different regions and countries will probably impose different regulatory rules, also related to the same frequency bands.
The resulting system requirements comprise four categories:

- Requirements for business, user and service. The main goal for these requirements is that the QoSMOS system should be competitive to other technologies by keeping the cost down and meeting users’ expectations.
- Requirements for system operation. It is also essential that the QoSMOS system is flexible and adaptable to differences in regulations given for the regions and markets in which it is intended to be deployed.
- Requirements for performance. In the end, the users’ experience will make the difference, thus the QoSMOS system’s technical performance should be good enough to meet users’ expectations of the service delivered.
- Requirements for architecture and complexity. This is the category most directly addressing architectural issues. The main aim is to ensure that the QoSMOS architecture complies with other external systems and enables flexibility and scalability.

The QoSMOS project has detailed a number of specific requirements under each of these headings, and the most important are highlighted below.

Keeping the cost of the system low and at the same time ensuring the technical and operational advancements is challenging. This is very much secured via the highly modular architecture chosen, as it is explained in the next chapter. Furthermore, regulatory compliance must be ensured, and this influences mostly the choices regarding the physical layer and transceiver architectures, but also how the whole system must behave in operation. This implies a high degree of interplay between the low level transceiver architecture and the core functions of the system, which in the end must be supported by specific functionalities, interfaces and protocols. The most important cognitive functionalities which QoSMOS has to provide in order to fulfil these requirements are:

- Interference avoidance
- Incumbent detection and protection
- Context awareness and response
- Transmitter power control
- Frequency independence

The QoSMOS system requirements reflect the needs from the use cases with respect to cost, regulatory compliance and flexibility.

Technical performance is of course necessary to meet users’ expectations as well as to ensure efficient use of spectrum. In the QoSMOS context, this concerns QoS management, mobility support and physical layer performance, key pillars of the project. The system functions enabling QoS management should include:

- Traffic differentiation and priority.
- QoS interworking with other systems.
- Maintaining QoS level and re-establishment of services.

Mobility support in cognitive radio systems has one additional dimension to user and terminal mobility, namely spectrum mobility. This means that handovers may be triggered also by the need for change of spectrum block used due to e.g. incumbent appearance. Proper interfaces are important enablers for achieving coexistence, therefore it is required that the QoSMOS architecture shall allow interworking with different kinds of opportunistic systems:

- Other QoSMOS systems belonging to the same operator.
- Other QoSMOS systems belonging to another operator.
- Other opportunistic systems belonging to another operator.
Equally important is the necessity to define interfaces with external entities essential for the system to comply with regulations:

- Towards regulation information repositories.
- Towards geo-location databases.

In order to be cost efficient and flexible in a heterogeneous environment, the architecture must support the selection, interworking and mobility across multiple radio access technologies (RATs). Finally, scalability and flexibility to accommodate the various scenarios and use cases described above are key properties of the architecture.

**SYSTEM ARCHITECTURE**

The diversity of the QoSMOS scenarios, like the examples selected in the previous chapter, requires a high degree of flexibility for the system architecture design. This chapter shows how this can be achieved for the various topologies with the functional reference model applied to the system architecture options.

**Topologies**

The system architecture design has to be flexible enough to support the various topologies envisaged for the realisation of the cognitive functions in the scenarios. In order to rationalise the different possibilities identified, two key system functionalities have been considered [2]:

- The control of the resource allocation, which can be done according to a centralised or, distributed topology.
- The control of the spectrum sensing operations which can be performed locally, or in a centralised or distributed topology.

Any QoSMOS system realisation can be characterised by a combination of those topologies for resource control and spectrum sensing. The commonalities and the differences identified among different realisations can be exploited for an efficient system design. As a result, with the four topologies’ combinations illustrated in Figure 4 all QoSMOS scenarios including the ones described previously can be addressed.

![Figure 4: Relations between the topologies’ combinations and the QoSMOS scenarios](image)

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Reference model

The reference model shown in Figure 5 captures the split of the system functions into a set of functional entities.

At the core of the reference model lays the two-fold Cognitive Manager for Spectrum Management and for Resource Management (CM-SM and CM-RM)[3]. The CM-SM is in charge of the management of the frequency spectrum allocated to, and for dedicated use by QoSMOS entities. The CM-SM acquires the relevant context information from global databases: the Common Portfolio Repository and the Regulatory Databases which provide environment information regarding spectrum sensing, spectrum regulations, operator frequency planning etc., and reflects this in the corresponding provision of the spectrum portfolio, which condenses all the above information for further use [2].

The main user of the spectrum portfolio is the CM-RM, which is in charge of provision of data service to upper layers (ULYR, e.g. user application or data path) using the spectrum opportunities and policies indicated by the portfolio in accordance with an agreed level of QoS. The CM-RM also provides the functionalities needed to implement incumbent protection, relying in that on a close cooperation with the CM-SM, which in turn implements incumbent protection on a spectrum management level[4] [5].

The cognitive managers have a direct control onto two other main functional blocks: the Transceiver is able to perform synchronised data transmission and to provide unidirectional or bidirectional dedicated broadcast and multicast channels on different spectrum bands operated by the supported heterogeneous radio access technologies. The Spectrum Sensing entity is responsible for controlling the sensing process by interacting with the sensor, for making decision (about the presence or absence of an incumbent for example) based on sensing measurements.

In addition, a seamless and RAT-agnostic communication between different functional entities is ensured by the Adaptation Layer. This mainly applies to the communication in heterogeneous configurations to facilitate the data exchange between different network elements. The Adaptation Layer is also in charge of ensuring scalability of the system and of checking the status of the different entities that are participating into the whole scenario. Furthermore, it is able to inform all entities about various events that may happen and whose impact could derive into misbehaviour and erroneous decisions.
Finally, the reference model also captures the interfaces with external (non-QoSMOS) entities, namely the Network Coordination which has, when applicable, the overall responsibility of the configuration of an operator’s infrastructure network, and the Upper Layers.

**Architecture options**

The system architecture design aims at defining how the functional entities are deployed within the network elements involved in each scenario. The variety of topologies combinations, as previously presented implies to consider several architecture options. However, some of these options share a number of characteristics that, once specified, may be commonly applied to several scenarios. It is then possible to focus on few options that provide all the elements necessary to cover the diversity considered in QoSMOS. In order to support this flexibility, four topological domains have been defined [2]. The terminating domain covers the wireless interface between user equipments (UE) and access points (AP) or gateways (GW) shown in Figure 1, Figure 2 and Figure 3. To the networking domain belong the functions controlling the other network elements. The coordination with neighbouring and related networks takes place in the coordination domain. Finally, the coexistence domain comprises roles of larger-scale coexistence (for example, regulatory repositories and common portfolio).

As an illustration, Figure 6 presents the architecture option for the Resource Control Centralised with Spectrum Sensing Centralised (RCC-SSC) topology combination mapped to the terminating, networking and coordination domains [2]. This topology combination is relevant for the cellular extension case with central resource control in the AP but also for an ad hoc network with a central controller acting as a GW. Functionalities present in the Core Network (CN) for the former case collapse in the latter case into the GW as shown in Figure 6. For the sake of simplicity, the Adaptation Layer (AL), described in the following section, is not shown in Figure 6, focusing on topology mapping.

The mapping of the QoSMOS functional entities results in a CM-RM entity located in network elements responsible of allocating the radio resources according to the portfolios provided by the CM-SM. This CM-RM entity covers both the terminating and networking domains. In parallel, the CM-RM entity, located in the UE, exploits the allocated resources to transfer its uplink data, and covers in consequence the terminating domain only.

Spectrum sensing is also centralised: the measurement’ results, coming from scattered sensors in the UEs or in the AP/GW itself, are merged and analysed in the GW or in the AP (networking domain). The output is then transferred inside the AP/GW, to both CM-RM and co-located CM-SM.

This option can be applied for scenarios using a RCC-SSC topology combination and operating with or without core network. Additionally, when focusing on the access point, the architecture relative to the spectrum sensing management is identical to the one required to RCC-SSL topology combination. Consequently, specifying spectrum sensing architecture in RCC-SSC implies the definition of this function for RCC-SSL as well.
Figure 6: Architecture option for RCC-SSC topology combination in both cellular extension (UE, AP, CN) and ad hoc network (UE, GW) cases.

DETAILED SYSTEM FUNCTIONS

This chapter describes detailed system functions illustrating the mapping of reference model and architecture options to network elements for dedicated scenario use cases.

Spectrum portfolio management

The use of whitespaces in CR networks is subject to specific regulations which are reflected in the Spectrum Portfolio Management described in this section. Figure 7 shows the RCC-SSC topology combination mapped to both extension (involving CN and AP) and ad hoc network (involving GW) cases as addressed in the previous chapter. As an initial step, which can be either proactively pursued to prepare for this or done as a reaction to a request, the CM-SM retrieves through the AL the required information from the relevant remote repositories. Once a portfolio request comes from the CM-RM, the CM-SM possibly responds with a portfolio deployment, which can either use a locally available portfolio or imply a next-level CM-SM entity (note the dashed line in the upper part of Figure 7).

When a portfolio is no longer needed, the CM-RM revokes it and this message is forwarded correspondingly to the relevant level of CM-SM entity (a revoked portfolio may be reused locally). A similar operation occurs when the CM-RM detects the presence of an incumbent by sensing measurements. A different trigger for a portfolio revocation comes from the repository side, as a consequence of relinquished rights, for example preparing an imminent appearance of an incumbent on the scene. These operations are illustrated in the bottom part of Figure 7.

From the deployed portfolio the CM-RM allocates operating channels for current use as well as reserve channels as a possible back-up, needed to cope with eviction from an operating
channel. Operating and reserve channels represent therefore the active subset of the deployed portfolio channels. During operation, the CM-RM may provide performance metrics, which are possibly forwarded to the common portfolio repository or used only locally, see Figure 7. Similarly, sensing measurements information concerning operating channels and/or inactive portfolio channels is possibly exploited at local and/or common portfolio level. This is illustrated in the following section.

Figure 7: Spectrum portfolio management - request and deployment, maintenance, and revocation

Sensing measurements
In CR networks, communication devices need to capture the current usage of the spectrum before establishing its own communication. This behaviour is referred to as detecting free spectrum channels by performing periodic sensing measurements in addition to spectrum database queries. The QoSMOS system exploits these measurements to complement and refine its knowledge of the spectrum utilisation, characterised originally in the global portfolio databases. These measurements have two complementary objectives: monitor the operating and reserve channels (this forms the active channels set) to detect the presence of any incumbent; and provide sensing information on other spectrum bands to identify alternative reserve channels. The former is controlled by CM-RM and the latter is managed by CM-SM.
In the example for the RCC-SSC topology combination mapped to the cellular extension case as depicted in Figure 8, sensing measurements are requested by the CM-RM to detect the incumbent users communicating in the active channels defined by the CM-SM through the Spectrum Portfolio.
The CM-RM entity is in charge of requesting the active sensing measurements from the SS entity, defining the measurements’ reports at a pre-determined periodicity. The CM-RM also analyses the policies sent by the CM-SM for scheduling the data transmission according to the specified quiet periods.

Upon the reception of the measurements’ request, the SS entity determines the most appropriate nodes where to perform these sensing measurements, and for each of them the method to be used (collaborative or cooperative) as well as the periodicity, the duration and the range of frequencies. It is then up to the TRX to execute the measurements during the quiet periods (pre-defined or not) and to report the results to the SS entity according to the requested periodicity. The results are sent back to the CM-RM entity through the AL which performs the data conversion and dispatches the results to both the CM-RM and the CM-SM entities.

**Resource Control & Incumbent Protection**

Resource Allocation and Control together with the Incumbent Protection are intrinsic functions to be provided by a CR system. In this section the cellular extension case is considered where the network elements involved for Resource Control and Incumbent Protection are the Base Stations denominated as APs in communication with each other and with the UEs as shown in Figure 9 and Figure 10.

The overall processes for Resource Control and Incumbent protection are described in Figure 9 where local spectrum sensing (SS) is assumed which means that the spectrum sensing measurements performed in the UE and in the AP (for uplink and downlink respectively) provide decision about the presence of incumbent users. When the CM-RM located at the UE...
receives a Service request received by the CM-RM from the Upper Layers, it initiates a Resource request towards the CM-RM located at the AP. The context information contained in the spectrum portfolio is checked by the CM-RM at AP side to control the resource allocation for the service – see previous section about spectrum portfolio management. If a resource (whitespace) is available for the opportunistic UE, the CM-RM at AP side answers by a corresponding resource allocation towards the CM-RM located at the UE which then confirms the service allocation towards the ULYR. At AP side the spectrum portfolio information is updated by the CM-SM upon information received from the CM-RM. The spectrum whitespace remains allocated to the opportunistic UE as long as no incumbent pre-empts it back. The detection of incumbent can be performed periodically by means of spectrum sensing requested at UE side by the CM-RM towards the Spectrum Sensing (SS) entity. If an incumbent appears, resource allocation is requested again by the UE over the CM-RM which may be acknowledged back positively if another resource is available; if not - as depicted in Figure 9 - the resource request is not acknowledged and the service request is then rejected.

![Figure 9: Resource Control and Incipient Protection for the cellular extension case](image)

An advanced framework for Incipient Protection proposed by QoSMOS is based on Interference Monitoring [6], combining the spectrum sensing and the geo-location database approaches. The Interference Monitoring is the process of measuring the possible interference level at the incumbent receiver, which aims at adjusting the transmission parameters (e.g., transmission power) at the operating AP to adapt a changing transmission environment. The monitoring will be performed at the monitoring nodes near the incumbent receiver. The concept of the Interference Monitoring is shown in the following figure, where the cellular extension scenario with its RCC-SSC topology combination is considered. Interference Monitoring is processed according to two phases as shown in Figure 10: the set-up phase; and the running phase. The set-up phase is for each AP which has monitoring capability to register its sensor information to the portfolio repository. This is supposed to be done when an AP is set up in the system. When an AP is newly installed the new sensor information can be registered also by this message, even if other monitoring nodes have been
doing the Interference Monitoring as in the running phase. In the running phase, the CM-SM in the AP can request the CM-SM in the core network to identify neighbouring APs which are located near the incumbent receiver and could perform interference measurements. The CM-SM in the core network may further send the portfolio repository the inquiries for the candidate APs for the measurements. After identifying the potential “Monitoring Node APs,” the CM-SM in the core network sends them a sensing measurement request so that these APs start monitoring interferences. The reports are sent back to the CM-SM in the core network. After receiving the measurement results, the CM-SM estimates CIR at the incumbent receiver and updates allowable transmit power of the opportunistic transmission. According to the updated allowable transmit power, CM-RM in the operating AP updates transmission parameters such as transmit power and/or channel to use, etc. This information are sent back to the CM-SM in the core network and also stored in the portfolio.

Figure 10: Incumbent protection based on interference monitoring

**Mobility Management**

Mobile UEs in CR systems must be able to adapt their settings to the most suitable operating frequency at each moment. One of the main reasons in cellular networks for changing their configuration is the variation of population in cells, not only the number of UEs served by a single AP, but also the resources requested by each of them. Consequently two kinds of mobility must be handled by the system: physical mobility (user mobility) with mechanisms
and procedures for adapting the cell load in order to accept new UEs inside a cell and spectrum mobility for the dynamic changes of the operating band for connecting a UE to an AP according to the availability of several frequency bands.

An example of Mobility Management combining both physical and spectrum mobility is presented in Figure 11. The cellular extension case is shown with two cells: Cell A serves a UE as Incumbent User with high QoS requirements ensured by the use of TV White Spaces and moving across the cell; Cell B will be destination of this Incumbent User following its mobility pattern. Cell B is populated by many UEs as Opportunistic Users exploiting TV White Spaces for enhancing their capabilities as well but with lower QoS requirements. The periodic sensing measurements reports performed in Cell A alert the system about the need of resources in the destination Cell B due to the Incumbent User’s movement. The message flow for triggering the request for resources at destination Cell B is marked with green lines. The blue ones display the signalling messages associated to the system reaction to the detected event.

![Figure 11: Mobility scenario in QoSMOS system](image)

In Cell A the sensing measurements are performed according to the methods described in previous section. The reports have to be analysed and sent to the CM-SM entity managing the Portfolio in the Core Network. The information flow in the AP starts at the Spectrum Sensing entity sending the reports to the CM-RM using the Adaptation Layer (1a and 1b). With (2) the CM-SM gets the reports and forwards those to the CM-RM located in the CN (3), which updates the Spectrum Portfolio making the network aware of the Incumbent User movement (4). The second part of the procedure takes place in Cell B for serving the Incumbent User which is entering the cell. Cell B is populated by Opportunistic Users operating in TVWS and using resources needed by the Incumbent User as new UE in this cell. It is then necessary to force handover (HO) from TVWS to licensed spectrum band for some Opportunistic Users so that the released resources can be reserved for the Incumbent User, cell B fulfilling then the high QoS requirements. Figure 11 shows how the Portfolio update triggers the forced handover for the
Opportunistic Users and how the associated signalling is performed by the QoSMOS blocks involved: first towards the CM-SM of the Access Point (5-6), then for the CM-RM (7-8) in charge of sending signalling to the UEs for reconfiguring their radios at TRX side (9).

Concerning the spectrum mobility as illustrated above, the initial status of the scenario spectrum is Cell A with an Incumbent User, and Cell B densely populated with Opportunistic Users. The mobility management is triggered by Cell B being informed about the prompt appearance of a new Incumbent User. In order to prepare itself for hosting this Incumbent, Cell B checks its spectrum reports for selecting the best frequency band. Since free spectrum in this cell is rather scarce, it is necessary to handoff some Opportunistic Users back to licensed bands in order to provide the Incumbent with the resources it needs. Once the bands used by Opportunistic Users are vacated, the Cell B is ready for serving the Incumbent User and the final handover can be performed. At the final state, all users have been changed their operational bands without losing connectivity and keeping their QoS levels as involved in the process.

**Summary**

This White Paper presents the three scenarios called ‘Cellular extension in White Spaces’, ‘Cognitive Femtocell’ and ‘Cognitive ad-hoc network’ and the resulting requirements for the QoSMOS system, which concern mostly stakeholders’ cost, system operation and performance as well as architecture and complexity. The cognitive system functions defined to fulfil these requirements for QoS support are represented in the overall QoSMOS system reference model applied to different topologies for Resource Control and Spectrum sensing in the scenarios selected. Detailing the information flows over the network domains for intrinsic cognitive system functions like ‘Spectrum Portfolio Management’, ‘Resource Control and Incumbent Protection’ as well as ‘Mobility Management’ shows the flexibility of the system architecture design achieved. The White Paper illustrates the capability of the QoSMOS system to provide required QoS for the mobile opportunistic users when ensuring the protection of the incumbents in different scenarios.

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