Quality Of Service and MObility driven cognitive radio Systems

FP7-ICT-2009-4/248454

QoSMOS

D3.4

Reference Protocol Stack for QoSMOS

Contractual Date of Delivery to the CEC:	31-Mar-2012
Actual Date of Delivery to the CEC:	31-Mar-2012
Editor(s):	Rainer Wansch (Fraunhofer IIS)
Author(s):	Ulrico Celentano (UOULU), Kazushi Muraoka, Masayuki Ariyoshi (NEC), Abdoulaye Bagayoko, Dorin Panaitopol, Philippe Delahaye (NTUK) , Xiaobo YU, Piraba Navaratnam, Klaus Moessner (UNIS), Atilio Gameiro (IT), Ferdinand Kemeth, Rainer Wansch (Fraunhofer IIS), Dominique Noguet, Vincent Berg (CEA)
Workpackage:	WP3
Est. person months:	28 PM
Security:	PU
Nature:	R
Version:	1.0
Total number of pages:	56

Abstract:

This deliverable D3.4 aims at the definition of relevant messages for distributing and requesting sensing measurement information. It takes the requirements imposed by the different entities in the QoSMOS system model, from the scenarios and existing standards as a basis to define the interfaces and the needed messages. It is not intended to implement a dedicated protocol stack - instead it as a generic approach to serve different implementations.

Keyword list:

Cognitive Radio, Spectrum Sensing, Protocol Stack

The research leading to these results was derived from the European Community's Seventh Framework Programme (FP7) under Grant Agreement number 248454 (QoSMOS)

Abbreviations

3GPP	3rd Generation Partnership Project
AACA	Adaptive Admission Control Algorithm
ACA	Admission Control Algorithm
ACV	Admission Control Validation
AL	Adaptation Layer
AP	Access Point
API	Application Programming Interface
APR	Arrival Priority
BS	Base Station
CDMA	Code Division Multiple Access
CE	Cognitive Engine
CFP	Contention Free Period
CIR	Carrier to Interference Ratio
CM	Cognitive Manager
CP	Contention Period
CTRL	ConTRoL
DA	Data Archive
DELTS	DELete Traffic Session
DEV	[network] DEVice
DOP	Dilution of Precision
DRX	Discontinuous Reception
EDCA	Enhanced Distributed Channel Access
EDCA/DRR	EDCA with Distributed Resource Reservation
EDCA/RR	EDCA with Resource Reservation
eNB	e Node B

E-OTD	Enhanced Observed Time Difference
GPS	Global Positioning System
GW	GateWay
I/F	InterFace
IACA	Initial Admission Control Algorithm
IEEE	Institute of Electrical and Electronics Engineers
IND	INDication
IRNSS	Indian Regional Navigational Satellite System
LOC	LOCalised context
LTE	[3GPP] Long Term Evolution
MAC	Medium Access Control
MG	Measurement Gap
MGT	ManaGemenT
MRN	Maximum RTTF Number
MSC	Message Sequence Chart
NC	Networking [domain] Cognition
NRTTF	Non-Real Time Traffic Fraction
OSI	Open Systems Interconnection
OTDoA	Observed Time Difference of Arrival
PF	PortFolio repository
REG	REGulatory repository
REP	REPositories management
REQ	REQuest
RF	Radio Frequency
RM	Resource Management
RRC	Radio Resource Control
RSP	ReSPonse

RSSI	Received Signal Strength Indicator
RTTF	Real Time Traffic Fraction
SAN	Spectrum ANalyser
SI	Service Interval
SM	Spectrum Management
SNR	Signal to Noise Ratio
SotA	State of the Art
SS	Spectrum Sensing
SS MGT	Spectrum Sensing ManaGemenT
SS SCTRL	Spectrum Sensing Sensor ConTRoL
SSC	Centralised Spectrum Sensing
SSD	Distributed Spectrum Sensing
SSID	Service Set IDentification
SSL	Local Spectrum Sensing
TC	Terminating (domain) Cognition
TDMA	Time Division Multiple Access
ToA	Time of Arrival
TRX	Transceiver
TTFF	Time To First Fix
TVWS	TV WhiteSpace
TXOP	Transmission Opportunity
UE	User Equipment
UERE	User Equivalent Range Error
U-TDoA	Uplink Time Difference of Arrival
WLAN	Wireless Local Area Network

Table of contents

List of figures

List of tables

1 Executive Summary

Deliverable D3.4 sets forth the work started and documented in D3.2 [D3.2]. Whereas D3.2 was more a common view on the sensing framework, we here focus on the protocol stack messages, the relevant requirements and how these are linked together.

First, in chapter 3, the system model for spectrum sensing is defined in more detail describing especially the interfaces between the spectrum sensing and the other building blocks of the system model. This is first done in a more abstract way to see how the spectrum sensing is involved in the overall system and giving an overview on the needed interfaces. The different sensing topologies centralised, distributed and local sensing induce a different partitioning of the building blocks inside the sensing framework (management and control block) and in the different equipment like user equipment, base stations and gate ways. A proper distribution of the functions is needed as the sensing always communicates for the measurement with the transceivers which have different capabilities in the different equipment. The functional architecture of the spectrum sensing is refined in chapter 3.2 and the interfaces are described with their main functionality. Message sequence charts for the different sensing topologies and for interference monitoring highlight how the messages for spectrum sensing are handled within the sensing part of the QoSMOS system.

Chapter 4 deduces and describes requirements from different standards, system blocks and from the QoSMOS system requirements. It starts with a recapitulation of the proposals from P1900.6 where interfaces for invoking spectrum sensing in a cognitive system have been defined. This is used as a baseline. Additionally, requirements from context acquisition in terms of determining the position of sensor and the different methods are described in the following sub-chapter. It can be shown that all existing (most of them already implemented in many equipment) fulfil the requirements as they have been set by regulatory bodies. It is therefore not necessary to introduce new methods here.

The remaining part of this chapter starts with defining requirements for the protocol stack messages from a QoSMOS system point of view. It takes the QoSMOS system requirements and relates them to 6 main functional ones for the protocol stack which are complexity, flexibility, sensor setting capability, sensor information distribution, sensor measurement results distribution and sensor decision results distribution. Next to that the interfaces between the spectrum manager, resource manager and the spectrum sensing are further defined and the main functions are set. To assure that the later proposed messages can be used by existing standards, requirement sets from LTE and IEEE 802.11 are introduced.

In section 4.6 the protocol stack messages and data fields are defined in detail. This is first done by setting a relation between the solution and the requirements. As it has been found that P1900.6 is a sound basis for the messages and many of the needed messages are already defined. Therefore, we used a subset of the existing messages and defined the missing messages to have a high flexibility and to minimize the number of messages needed for the spectrum sensing. In this process, work-packages 2, 4, 5 and 6 were involved to reflect their needs. The different fields are then mapped to the different interfaces and are defined in Table 5-2, Table 5-3 and Table 5-4. In the final chapter 5.3, the QoSMOS data fields are grouped in 4 groups: sensor information (SensorInfo), sensor setting (SensorSet), measurement and sensing result. In Table 5-5 we also established the relationship between the message fields and the related QoSMOS system requirements.

2 Introduction

This deliverable deals with the protocol stack for QoSMOS. It sets forth the results described in deliverable [D3.2] in which the framework for sensing and the relevant building blocks have been introduced. Within this document the framework for radio context acquisition is further refined and the relevant message sequence charts for the different sensing topologies and interference monitoring are introduced in chapter 3. The structural architecture and the relevant interfaces are described which relate to the Cognitive Manager for Resource Management (CM-RM), the Cognitive Manager for Spectrum Management (CM-SM), the Transceiver (TRX) and the sensing blocks.

Chapter 4 describes the requirements set by different standards – like IEEE P1900.6, LTE, and IEEE 802.11 – and by the relevant functional blocks of the QoSMOS architecture. These requirements are the basis for the generation of the messages inside the QoSMOS protocol stack. To see how these requirements are reflected in the messages each message will be cross-referenced to the relevant requirement in chapter 4.6. The messages are defined for the relevant interfaces.

Flexibility is one of the most important requirements for the QoSMOS protocol stack. To cover this, the focus is on the definition of the messages as they can be transported through the different standards. With this, we can achieve an implementation in the most flexible way – leading to an implementation in the overall QoSMOS system approach.

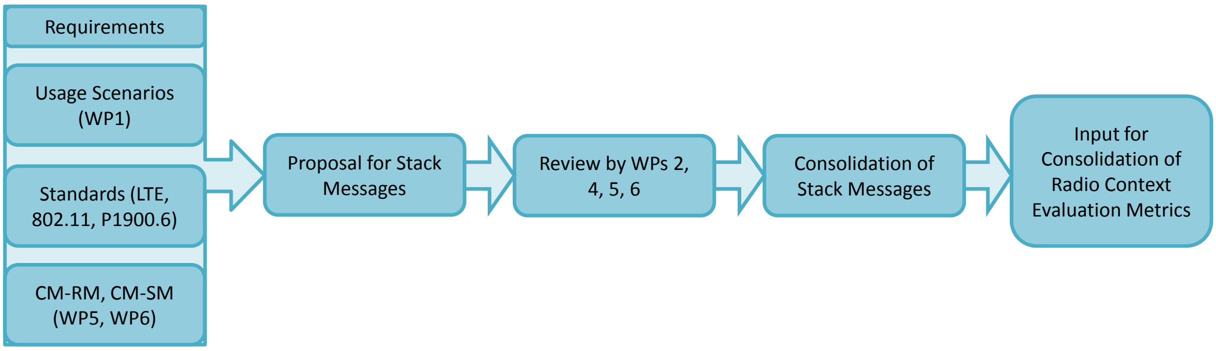

Figure 2-1: Approach for generation of protocol stack messages

Figure 2-1 shows the approach used to generate the protocol stack messages. As baseline the requirements from the usage scenarios (established in WP1), from existing and evolving standards and from the two cognitive managers in QoSMOS were collected. With this a first set of messages was created and reviewed by WPs 2, 4, 5 and 6. After this review a consolidated version of the protocol stack messages as they are described in chapter 4.6 has been achieved.

3 Framework for Radio Environment Context Acquisition

The scope of the work reported with this document is to identify and present a framework for spectrum sensing, which includes the architecture with its functional blocks and interfaces.

Radio context may more generally include performance metrics such as other forms of measurements provided by the lower layers at the transceiver to higher layer blocks (e.g., CM-RM). This deliverable focuses on measurements peculiar to cognitive radio systems and in particular spectrum sensing and interference monitoring.

Section 3.1 describes the functional architecture used for the acquisition of the above radio environment context, section 3.2 discusses the interfaces involved and finally section 3.3 illustrates the use of the functional blocks and the interfaces with the aid of Message Sequence Charts (MSC).

3.1 System Model

The portion of the QoSMOS reference model relevant to this deliverable, focusing on spectrum sensing (SS), is depicted in Figure 3-1. The reader is guided to [D2.3] for a complete discussion for the overall model and to [D4.2] for additional discussion on the relationships with the transceiver functional block. In particular, the interfaces CM1 (dedicated to the interaction of cognitive managers) and TX1 (includes the data path and the TRX control) shown in the figure are not further discussed in this deliverable. An overview of interaction over CM1, briefly discussed shortly below, is available for example from [Celen11]. The internal architecture of the SS block is depicted in Figure 3-3.

One of the main roles of the Adaptation Layer (AL) is to provide communication between remote functional blocks. Since the presence of the AL is partly dependent on the scenario [D2.2], the interfaces may assume different names depending on whether the AL is used or not. Therefore, the interaction between two functional blocks may happen through different interfaces, thus creating two sets of interfaces: those making use of the AL and those not making use of it[1]. Both sets are reported in Figure 3-1, but for clarity the name not referring to the AL is used in the following, with no assumption, however, on the absence of the AL in the given context.

[1] Interface SS1 includes SS1a towards the CM-SM and SS1b towards the CM-RM. When the AL is explicitly considered, these are made of AL1a from AL to CM-SM, AL1b to CM-RM, and AL1c to SS [D2.3]. SS2, always included within the same local entity, is not involved with the AL.

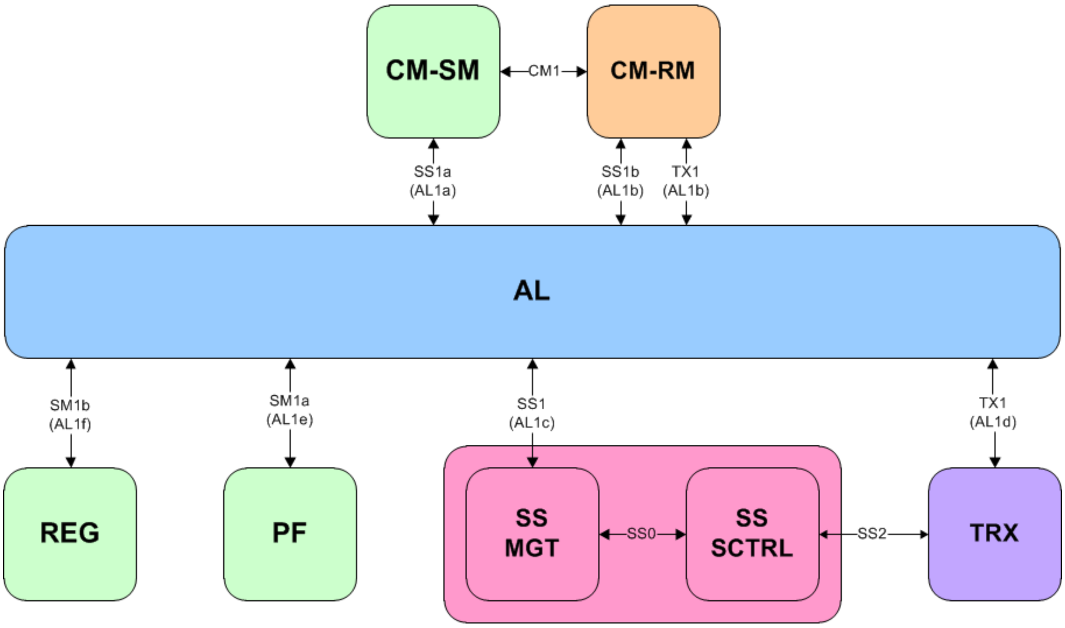

Figure 3-1: The relevant part for spectrum sensing of the QoSMOS functional architecture

The CM-SM is responsible for accessing the relevant repositories to generate a spectrum portfolio of available opportunities. The information may include results of spectrum sensing decisions provided by the SS. The CM-RM is responsible for providing service to the upper layers, up to the application and, to this end; it gets the spectrum portfolio deployed by the CM-SM [Celen11]. The CM-RM has the duty of efficiently managing the spectrum resources; in addition, it is responsible of protection of incumbent and therefore it may need spectrum sensing decisions from the SS [Mange11].

Whether the use of repositories such as databases or sensing measurements is mandatory or optional depends on the operating conditions and in particular on the applicable regulatory regime.

In order to avoid path duplicity, sensing decisions are delivered by the SS through a single interface SS1 (AL1c) towards the AL, which is responsible of the delivery of messages between itself and the CM-SM and CM-RM.

The main emphasis in this report is on SS1 and SS2 external interfaces, together with the internal SS0, see also Table 3-1 discussed later. It is worth mentioning that radio environment context acquisition, in its more general meaning, happens also over TX1. In fact, the CM-RM uses physical layer measurements provided by the TRX to support the quality of service it has to deliver [D2.2] [D6.2].

The SS gathers the raw sensing measurements from the TRX (and therein from the RF) through the interface SS2. Spectrum sensing measurements are controlled by the Sensor ConTRoL (SS SCTRL) functional block. The SS SCTRL, one or more entities of it depending on the sensing topology used [D3.2], passes those measurements to the ManaGemenT (SS MGT) functional block[2], which is in charge of delivering the spectrum sensing decisions to the functional blocks in need of them. Along the interfaces SS1 and SS2 flow also the messages about constraints, capabilities and configuration related to sensing.

[2] To this end, the SS MGT includes a multi-sensor processing unit.

The reason for the split between SS SCTRL and SS MGT is mainly for easing mapping the functional blocks depending on the topology [D3.2], and this is done by exploiting the so-called topological domains [D2.2] [Celen11]. Three sensing topologies, depicted in Figure 3-2 are identified: local, centralised and distributed sensing [D2.3].

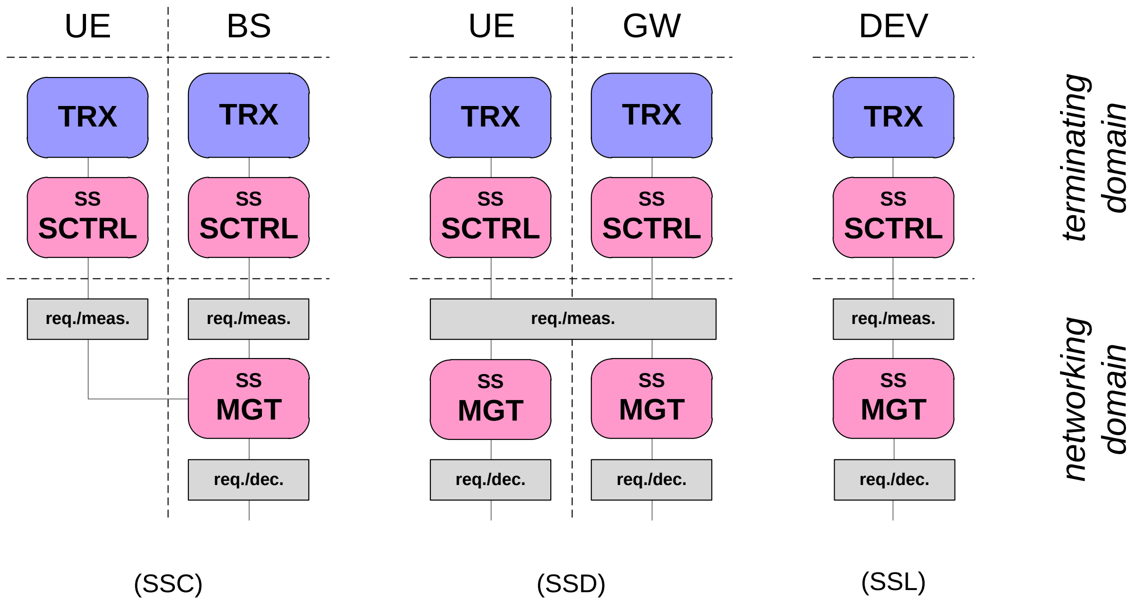

Figure 3-2: Centralised, distributed and local spectrum sensing topologies

With the simplest form of spectrum sensing, Local Spectrum Sensing (SSL), the entire process happens locally within a single network DEVice (DEV): spectrum sensing measurement(s) is (are) gathered, a decision is generated and the sensing result is finally used. Examples of local sensing are: the sensing scheduled and done over an operating channel at an opportunistic terminal engaged in communication for incumbent protection; or the sensing done over portfolio channels at an opportunistic network device for portfolio maintenance.

With Centralised Spectrum Sensing (SSC), measurements are cooperatively/collaboratively done at scattered locations. Those measurements are then collected by a central node, which generates a decision using those measurements, and then possibly further distributed to the other devices. When all sensors observe the same channels or incumbents, this mitigates the hidden incumbent problem and compensates for sensing impairments improving the sensing reliability. Conversely, when the sensing measurements are complementary, the benefit is a reduced load over individual sensors. In a cellular scenario, the sensors may be located at the User Equipment (UE) with the centre represented by the Base Station (BS).

Whereas centralised sensing improves sensing reliability, as with any centralised architecture, it is sensible to failures of the fusion centre. Moreover, the entire sensing process to a remote node includes a further step for the distribution of the sensing decision. Distributed Spectrum Sensing (SSD) is similar to the previous case, but measurements are shared among all network devices, which are all therefore able to generate locally a sensing decision at each UE[3]. The improvements in robustness over the previous one are gained at the expense of an increased load over individual nodes and higher

[3] Not all the functionalities are shared equally among all peers, but some are still concentrated in a GateWay device (GW), selected among the peers [Celen11].

complexity demands for them. For the reasons above, a distributed architecture may be preferred in some cases, and especially when a distributed architecture is already in place for resource management and all peers need the availability of a sensing decision [D2.3]. The above topologies impact on the mapping of spectrum sensing topologies onto the network devices. In case of SSC, measurements are needed from scattered locations. The measurements provided by those SS SCTRL blocks at terminating domain are then collected at a central node, such a fusion centre, being therefore in the networking domain, where the SS MGT resides. However, in case of local sensing, and also in the case of distributed sensing, even with some differences, the SS SCTRL and SS MGT are co-located at the same network node, but still residing in their respective domain.

The sensing protocol stack must support all the diverse target scenarios [MacKe11] in the most flexible way [D1.4]. The comparison of the above sensing topologies is described in Figure 3-2. The corresponding message sequence charts are described in Sect. 3.3.

Figure 3-3 shows the interfaces relevant to spectrum sensing. Depending on whether the AL is explicitly considered in the definition of the interfaces, different naming applies (see also Figure 3-1 and the related text). The names used in Figure 3-3 are not referring explicitly to the role of the AL.

The sensing result delivery latency includes the sensing duration, the exchange of commands and results (including to /from all involved remote sensors, if applicable), the processing of the decision (e.g., at the centre when applicable), and the distribution of the decision to the requesting entity. The sensing result delivery latency may possibly be used by the SS to select and tune the sensing method and algorithm. Depending on the sensing method and algorithm, a sensing reliability is associated. This can be expressed by probability of detection, probability of false alarm, or other derived metrics. Of course, there may be trade-offs between sensing delivery latency and reliability. Therefore, these quantities are used by the SS during the negotiation with the requesting functional block (see for example [D5.2]).

3.2 Functional Architecture and Interfaces

To further define the interfaces in the spectrum sensing framework, Figure 3-3, we use a slightly updated spectrum sensing reference model as it was introduced in [D3.2]. One of the main changes is the interface SS0, which is actually twofold. It serves as interface between the SS MGT and the SS SCTRL, regardless if they are located within the same unit or if they are distributed among different units. As mentioned before, the model is introduced in a way that the interfaces are designated with two names to highlight that they can use the AL or not. For the further definition we will stick with the AL free designation.

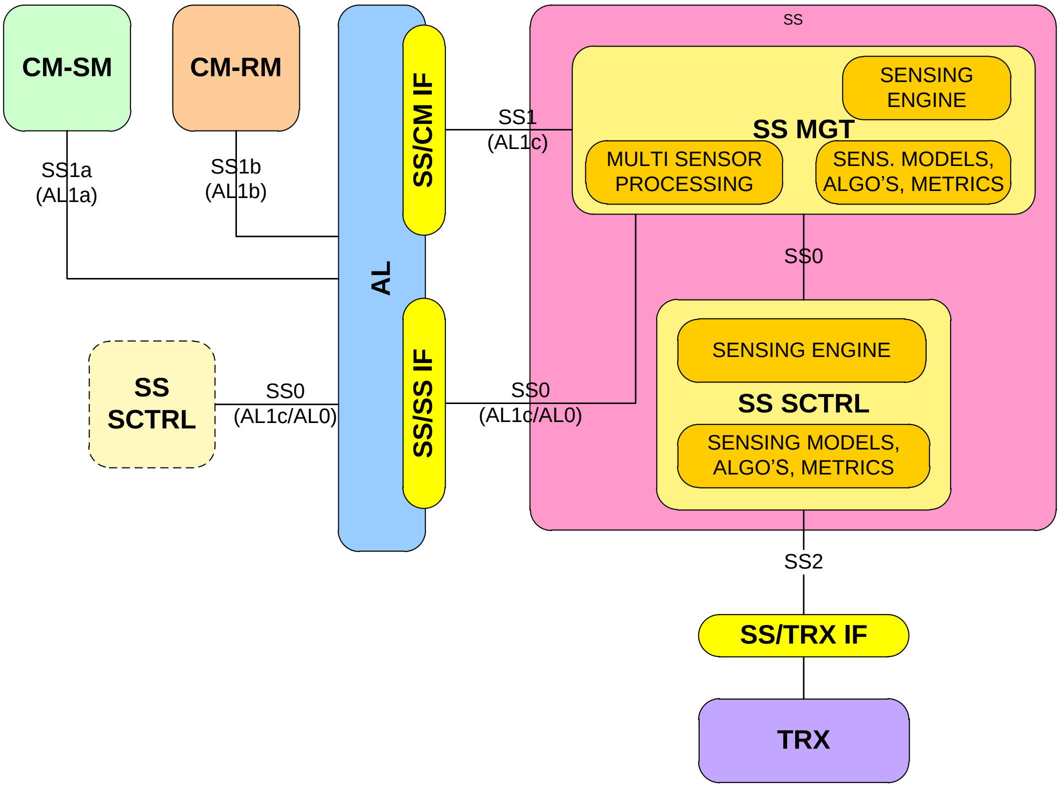

Figure 3-3: Reference system model for spectrum sensing

The following Table 3-1 summarizes the interfaces as they are defined in the spectrum sensing system model shown in Figure 3-3.

Table 3-1: External and internal interfaces related to spectrum sensing

interface	Description
SS0	SS MGT requests measurements from SS SCTRL SS SCTRL provides measurements to SS MGT SS MGT and SS SCTRL negotiate parameters and constraints SS MGT and SS SCTRL can be located in different entities
SS1 (AL1c)	SS receives from CM-RM/SM spectrum sensing requests SS provides to CM-RM/SM spectrum sensing decisions SS negotiates with CM-RM/SM related parameters and constraints
SS2	SS requests and gathers raw measurements from TRX SS negotiates with TRX related parameters and constraints

The use of the spectrum sensing interfaces is further illustrated by message sequence charts in section 3.3.1. In order to have spectrum sensing configured and set-up, some parameters need to be exchanged. Those parameters are listed in Chapter 4.6, where the interfaces used and the functional blocks involved are indicated (see also [D7.2]).

Corresponding to the reference model for sensing, there are two external and one sensing interface which can be internal or external we have to care about.

Spectrum Sensing Management-Spectrum Sensing Sensor Control Interface and the Sensing-Sensing Interface SS0

One sensing internal interface called Spectrum Sensing Management-Spectrum Sensing Sensor Control Interface can be identified. Information about sensing periodicity, detection sensitivity, spectrum sensing measurements and physical constraints is exchanged there.

The interface between different sensing entities is called Sensing-Sensing Interface and exchanges information about spectrum sensing measurements and physical constraints. The spectrum sensing can be organized as collaborative, cooperative or distributed sensing.

Name: SS0
Type: interface
Needs/Inputs: exchange data about detection sensitivity, decision and transceiver information.
Provides/Outputs: exchange data about detection sensitivity, decision and transceiver information
This interface includes the management of the different tasks in the other functional blocks of the sensing.

Sensing-Resource Manager/Spectrum Manager Interface SS1

Over this interface the Spectrum Manager requests a Spectrum Sensing block for sensing the spectrum and Spectrum Sensing Measurement Data and Output of the sensing process are exchanged.

Name: SS1
Type: interface
Needs/Inputs: data from internal functional blocks and from external entities
Provides/Outputs: data to internal functional blocks and from external entities
This block manages the data flow between the internal blocks in the sensing and to the external entities within the system.

Sensing-Transceiver Interface SS2

The Sensing-Transceiver Interface is defined between the spectrum sensing framework and a physical transceiver unit to obtain information about baseband and physical sensing. This interface is also used to exchange configuration data.

Name: SS2
Type: interface
Needs/Inputs: information about different kinds of sensing from the transceiver entity.
Provides/Outputs: configuration data as defined later in the document to the transceiver entity.
This interface includes the management of the different tasks in the other functional blocks of the sensing.

3.3 Relevant Message Sequence Charts

3.3.1 Spectrum Sensing

3.3.1.1 Local Spectrum Sensing

The simplest form of spectrum sensing is depicted in Figure 3-4. In the figure, a configuration phase is assumed to be proactively done before a sensing decision is needed, but it can also be performed just before the sensing process starts. First the sensor is configured within the SS domain and then the SS SCTRL block performs the relevant settings on the underlying transceiver.

A sensing decision request can come by either the CM-RM or the CM-SM. As anticipated in section 3.1, the AL may avoid duplicity of paths, especially when a sensing result is to be exploited at both cognitive managers. For this reason, a sensing decision request may come from the AL, as illustrated in Figure 3-4.

In section 3.1 it has been pointed out that the selection of the sensing configuration may be conditioned by constraints on sensing performance, such as sensing reliability or latency. In this section, it is assumed that local sensing is selected. The sensing request propagates from the SS MGT through the SS SCTRL down to the TRX and the result proceeds correspondingly in the opposite direction.

Once the sensing decision is available at the SS MGT, it is further delivered at the requesting entity (CM-RM, CM-SM, AL, see above). As said, the AL may dispatch the result to the requesting cognitive manager or to both.

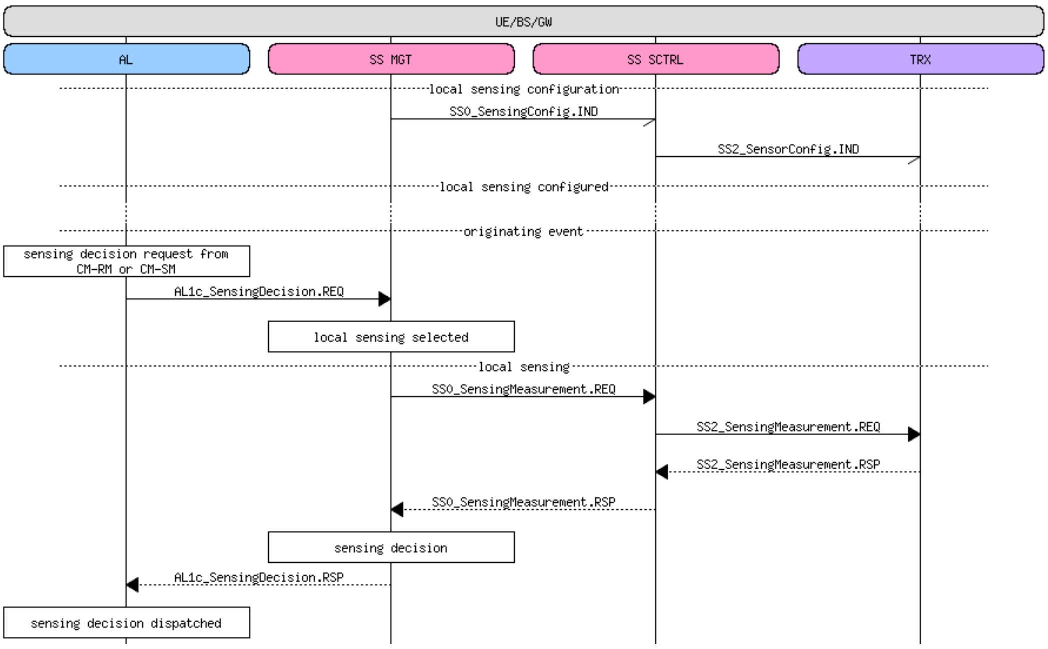

Figure 3-4: Messages for local spectrum sensing

3.3.1.2 Centralised Spectrum Sensing

As observed, sensing performance can be improved by combining more results. Figure 3-5 shows how the sensing process is transformed in this case. After a preliminary configuration phase and upon reception of an originating event (see section 3.3.1.1 for a discussion on these), a centralised sensing process is initiated. The SS MGT at the fusion centre issues the sensing measurement requests to all the involved sensors, UE1, UE2 and BS/GW itself in the figure. Again, the request propagates down to the TRX in parallel at each node. Finally, all the responses are collected at the fusion centre where the sensing decision is generated and delivered at the requesting entity.

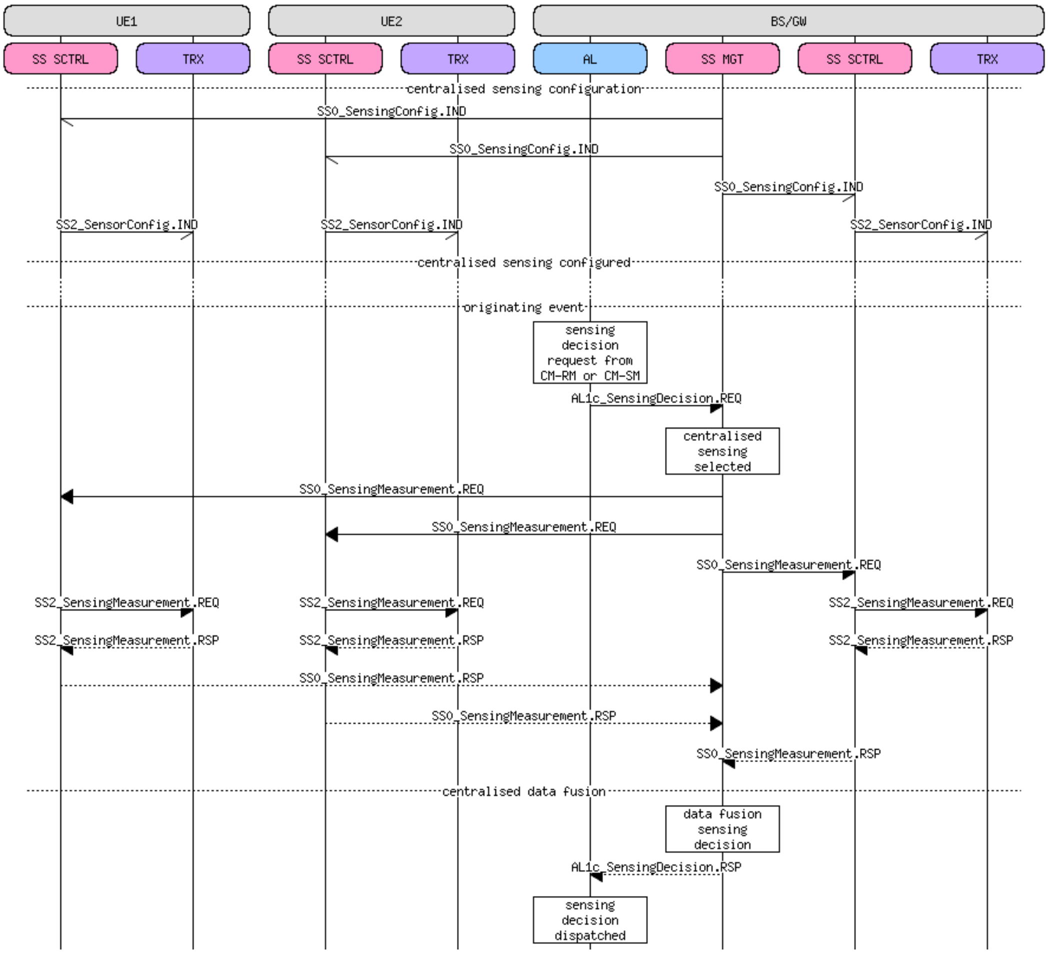

Figure 3-5: Centralized spectrum sensing (simplified representation)

The simpler Figure 3-5 is easy to focus on the process and describes it logically. For practical reasons, communication between remote nodes occurs through the AL [D2.3]. The signalling involved when those interfaces are taken into account is presented in Figure 3-6. The difference is that the message from the initiating SS MGT to the remote SS SCTRL entities goes through the AL. The message is first sent by the SS MGT to the interface AL1c, then it travels to the remote sensors through the interface AL0, and finally it reaches the intended SS SCTRL destinations from AL1c.

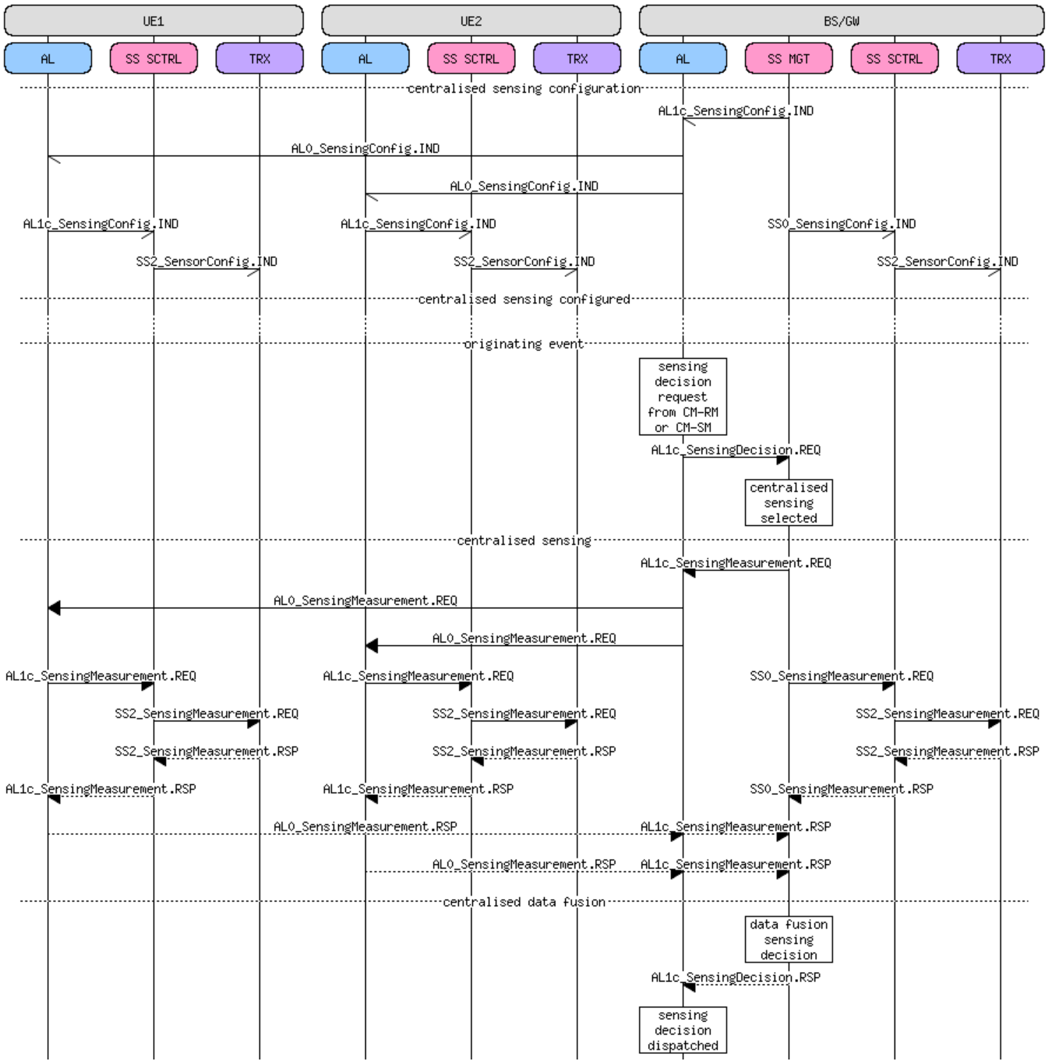

Figure 3-6: Centralized spectrum sensing (complete representation)

3.3.1.3 Distributed Spectrum Sensing

The distributed spectrum sensing, illustrated in Figure 3-7, is in some sense a generalisation of the centralised sensing. In this case, any node is able to generate a sensing decision out of more measurements, as done by the fusion centre in the RRC case. Similarly to the previous cases, a preliminary configuration phase and the originating event are shown (see section 3.3.1.1 for a discussion on these). However, since the protocol is distributed, the configuration phase may include agreement on the settings. For example, this is needed when the sensing targets are allocated non-uniformly to the sensors in order to reduce the sensing overhead to individual devices (see sensing on non-overlapping sets [D2.2]).

In SSC, the same SS MGT entity issues the sensing requests to the SS SCTRL blocks and collects from them their measurements. This causes a clean sequence of request/response (REQ/RSP) pairs because the fusion is always performed at the device initiating the sensing process and issuing the request messages. In SSD, the SS SCTRL at a non-initiating device is able to generate locally a sensing decision also using the distributed measurements, which are shared in broadcast/multicast. For this reason, sensing measurements available at a non-initiating device are delivered to the local SS MGT by indication (IND) messages.

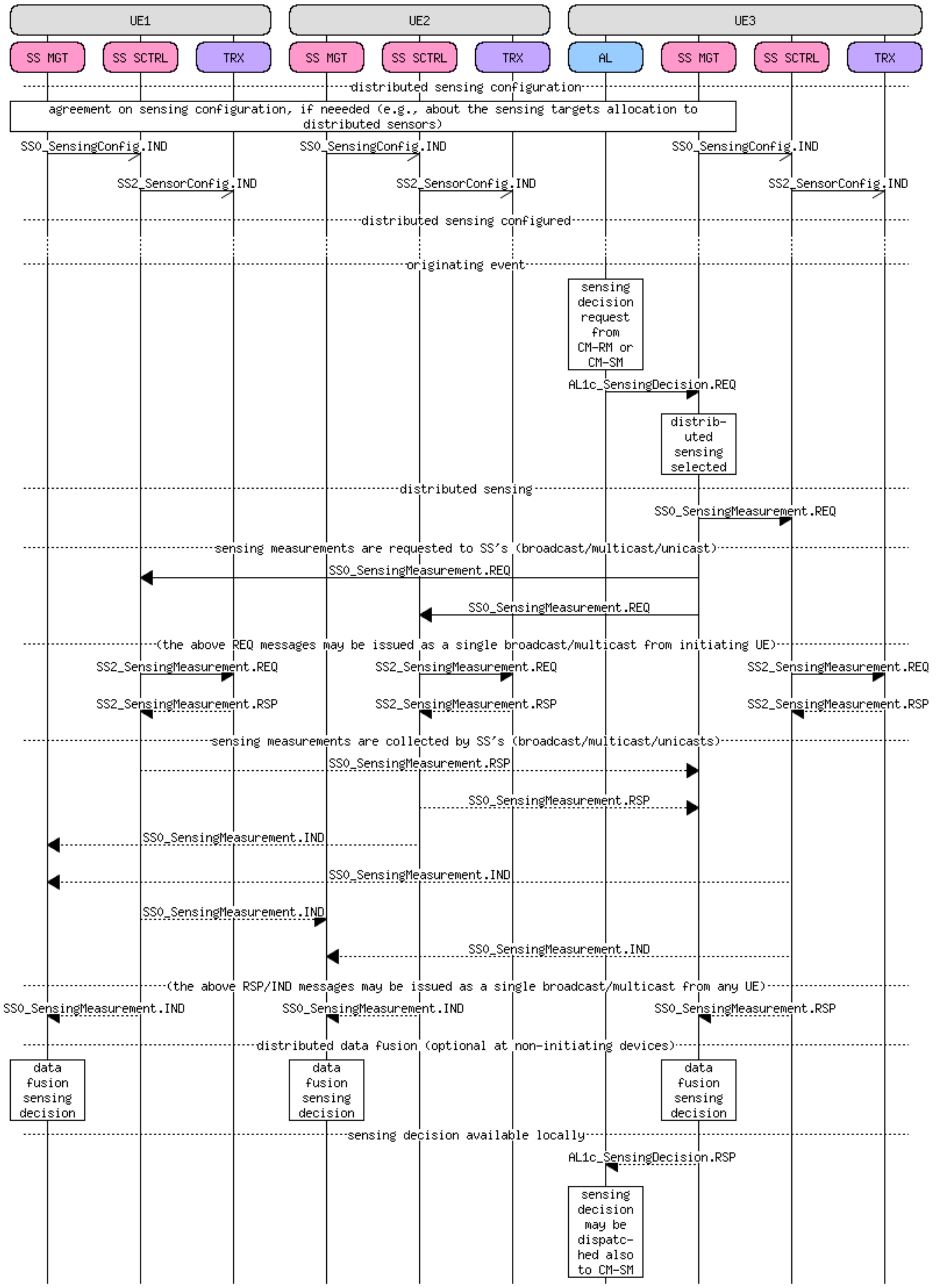

Figure 3-7: Distributed spectrum sensing (simplified representation)

As with SSC, the process is described logically with the simpler Figure 3-7. As observed in section 3.3.1.2, the communication between remote nodes occurs through the AL [D2.3]. The corresponding signalling is presented in Figure 3-8, where, similarly to the previous discussion about Figure 3-6, it is shown how the messages to remote entities travel from AL1c, through AL0, and finally to AL1c.

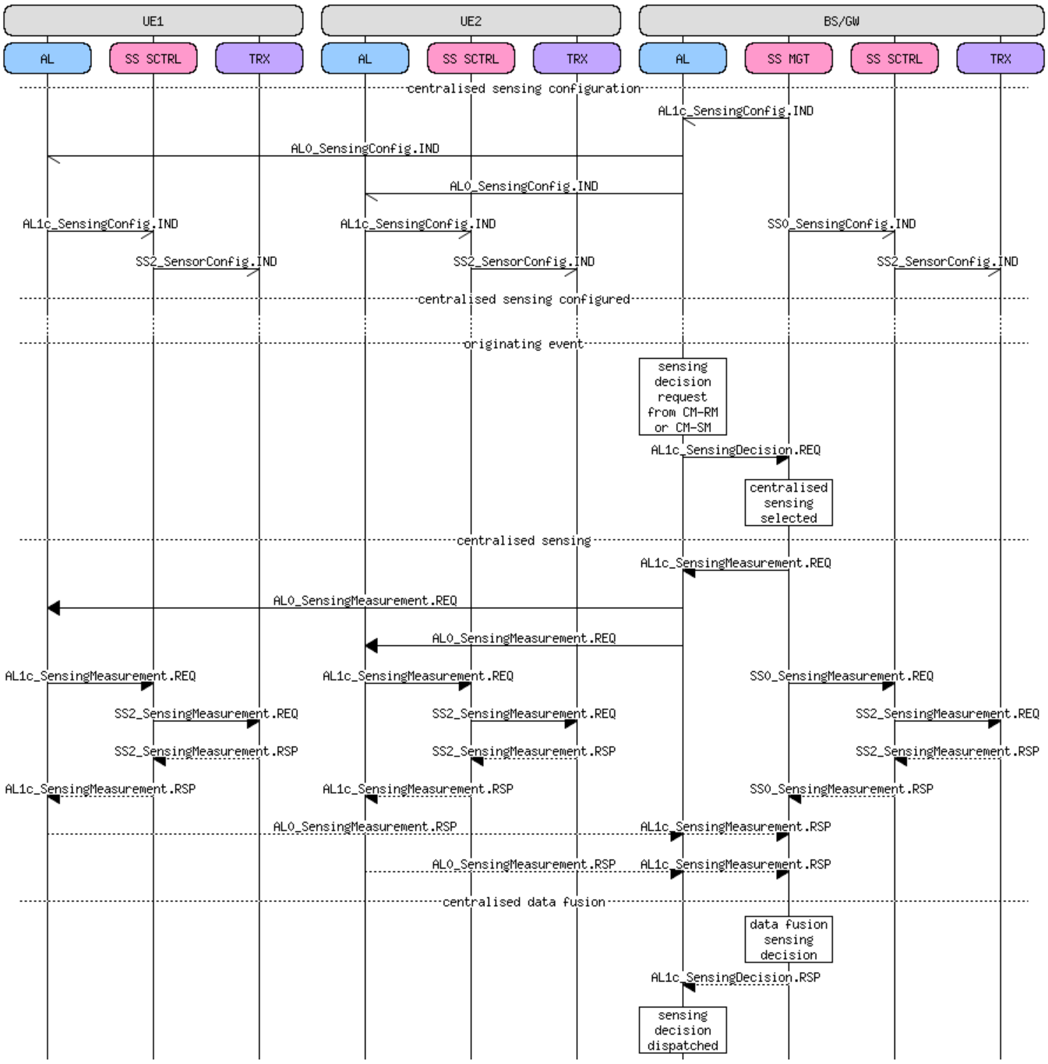

Figure 3-8: Distributed spectrum sensing (complete representation)

By comparing SSC and SSD (i.e., Figure 3-5 with Figure 3-7; or Figure 3-6 with Figure 3-8), the signalling with distributed sensing is seemingly complicated. However, considering that what appears in the MSC as a bunch of point-to-point messages from the initiating device to the distributed sensors, is in practice realised as broadcast/multicast messages.

3.3.2 Interference Monitoring

Incumbent protection is a key requirement for the opportunistic spectrum access. interference monitoring has been proposed [D3.2], [Murao11] as one of the incumbent protection techniques, that combines the spectrum sensing and geo-location database approaches. The concept of the interference monitoring for cellular extension scenario is shown in Figure 3-9. In this technology, a monitoring node located near the incumbent receivers measures both the interference level and the incumbent signal level. Using propagation estimation in addition to the measurements, CM-SM estimates Carrier to Interference Ratio (CIR) at the incumbent receiver and adjust the allowable transmit power for the opportunistic TX so that the CIR at the incumbent receiver can be kept at sufficient level. Owing to the combination of the sensing and the propagation estimation, the accuracy of the CIR estimate at the incumbent receiver improves.

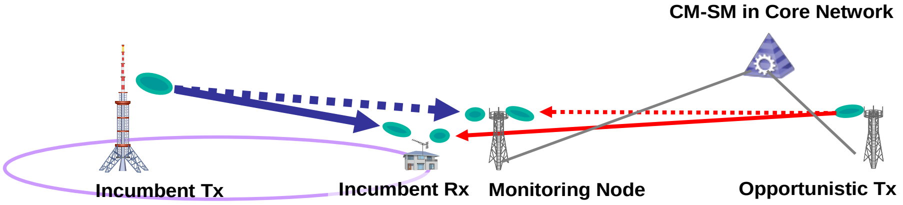

Figure 3-9: Interference monitoring concept

The procedure for the interference monitoring is presented in [D2.3]. This section updates and elaborates the procedure in a particular focus on the spectrum sensing entity which measures interference and incumbent signal. The procedure for the interference monitoring is shown in Figure 3-10, and the primitives involved in the interference monitoring are summarised in Table 6-1 in the annex. The interference monitoring procedure is divided into two phases: the preparation phase; and the running phase.

The preparation phase is for each BS which has monitoring capability to register its sensor information to the Prtfolio Repository (PF). This is supposed to be done when a BS is set up in the system. When a new BS is added, this procedure for sensor information registration can also run even if the interference monitoring has been operating in the running phase.

In the running phase, the CM-SM in the BS initiates the interference monitoring. CM-SM in the core network requests the sensor information from the PF and the incumbent system information from the REGulatory databases (REG). Using this information, the CM-SM selects a monitoring node(s) which is located near the worst-case incumbent receiver which will receive the largest interference from the operating opportunistic TX. Then, the CM-SM sends the request for measurement to the selected monitoring node, which also specifies the sensing information such as target channel and time etc.

SS MGT in the monitoring node receives the request from the local CM-SM. Through SS SCTRL, the SS MGT notifies the TRX to receive the radio signals in the target channel and time. SS SCTRL calculates the interference power and incumbent signal power based on the received baseband signals provided by TRX. Then, the calculated measurement results are sent to SS MGT. If needed, the received power of the interference and incumbent signal can be quantised at SS MGT. The SS MGT reports the signal levels to the CM-SM in the core network. Note that adaptation layer between the SS MGT and CM-SM is not shown in Figure 3-10 for simplicity.

After receiving the measurement results, the CM-SM in the core network estimates CIR at the incumbent receiver and updates the allowable transmit power of the opportunistic Tx, which are addressed more in detail in [D6.3]. According to the updated allowable transmit power, CM-RM in the opportunistic Tx determines operating parameters such as the operating transmit power or the channel to use. This information is sent back to the CM-SM in the core network and also stored in the PF.

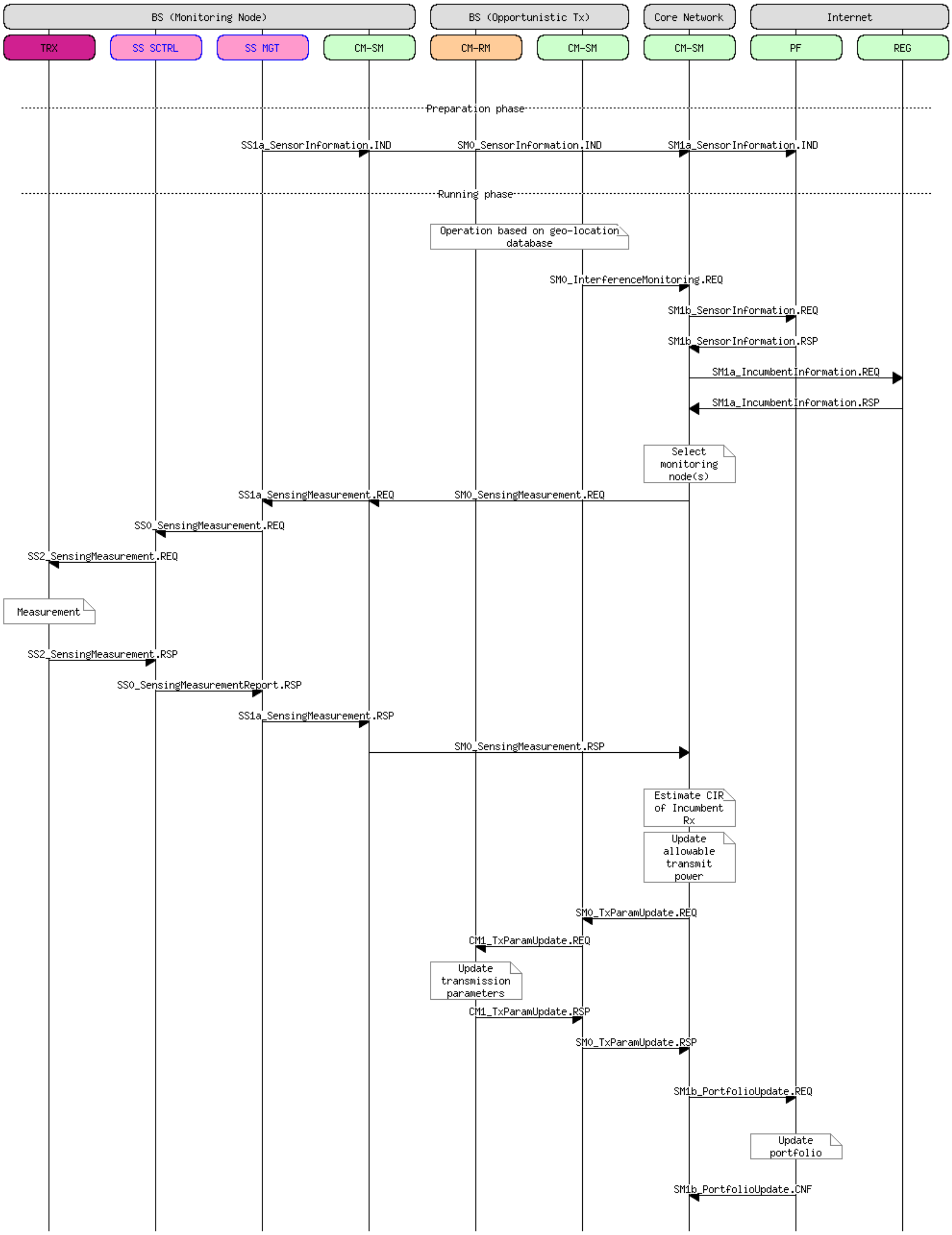

Figure 3-10: Procedures for interference monitoring

4 Requirements for Radio Environment Context Acquisition Protocol Stack

To settle the requirements for the protocol stack messages first a short recapitulation on the capabilities and definitions proposed by P1900.6 [P1900] is given. Additionally, a short overview on the SotA on position acquisition is given. Then, the main requirements are derived from the QoSMOS system requirements and the related building block CM-RM and CM-SM. To complete this, these requirements are completed with those imposed by LTE and IEEE 802.11.

4.1 Specification as Proposed by IEEE1900.6

The scope on the IEEE DYSPAN 1900.6 group relates to "Spectrum Sensing Interfaces and Data Structures for Dynamic Spectrum Access and other Advanced Radio Communication Systems". IEEE 1900.6 standardizes the information exchange between spectrum sensors and their clients in advanced radio communication systems in a technology neutral way. Indeed, the logical interface and supporting data structures used for information exchange are defined abstractly without constraining the sensing technology, client design, or data link between sensors and their clients. This means that the protocol stack on the information exchange channel is not specified with and implementation approach in mind but rather describe the architecture of such a structure. A first version of the IEEE Standard 1900.6-2011 was published on April 22nd 2011. [Moess11] and [Murro11] recap the main concepts developed in the standard. Figure 4-1 gives an abstract view of the above-described scenario and illustrates different interfaces between spectrum sensors and their clients as defined and considered in the scope of 1900.6.

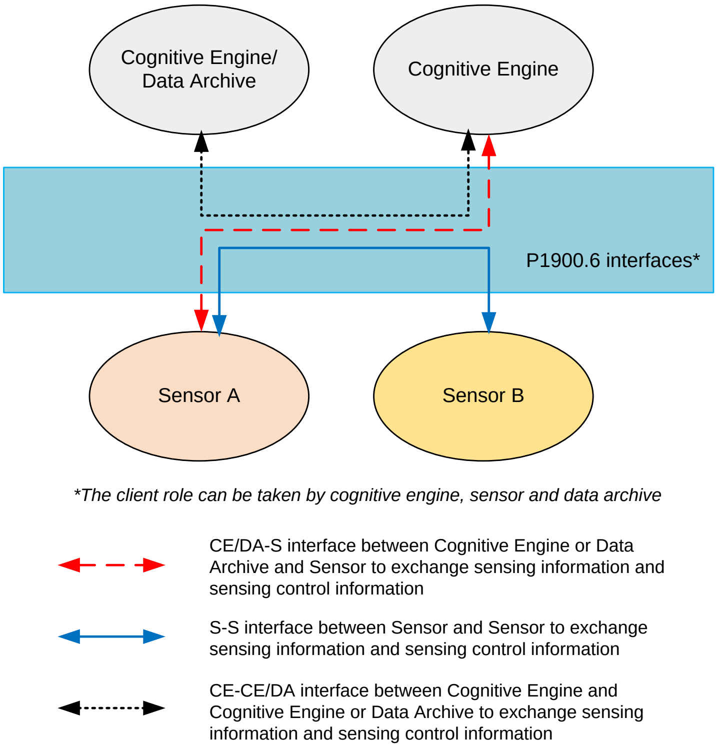

Figure 4-1: IEEE 1900.6 interface definition

The standard considers three types of logical interfaces: the interface between Spectrum Sensors (S-S interface), the interface between Cognitive Engine or Data Archive and Sensors (CE/DA-S interface), and the interface between Cognitive Engines and Data Archives (CE-CE/DA interface). Since service primitives defined for these interfaces partly overlap in functionality, the resulting logical model includes options to forward sensing related information across multiple realizations of a CE or DA entity, such as in common radio access networks where CE or DA might be collocated with base stations. Future extensions to the standard hence will allow interfacing sensors with external entities, such as geolocation databases. IEEE 1900.6 logical entities rely upon platform services that are by intention not specified further by the standard. Instead, the standard specifies the service access points as well as the data structures exchanged across these service access points (Figure 4-2).

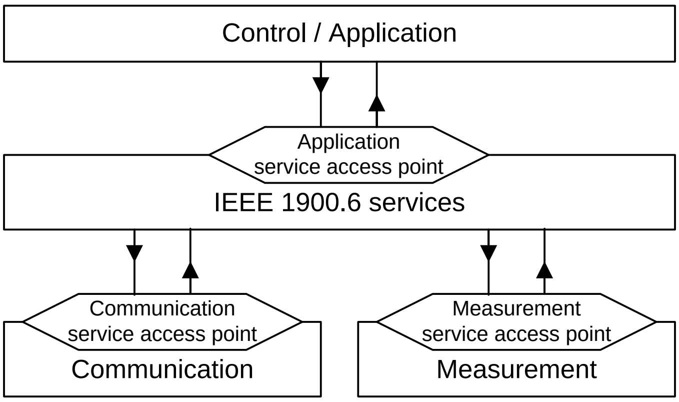

Figure 4-2: IEEE 1900.6 interface definition

Logical interfaces are realized through communication services provided by the platform, depending on the logical entity realized and its specific communication demands set by the application scenario and its specific configuration. In this interface architecture the subsystems are as follows:

The **application and control subsystem** is an abstract user of the IEEE 1900.6 services utilizing the application service access point realized by the 1900.6 services to access spectrum sensing. For example, a control and management entity of a wireless network may access IEEE 1900.6 spectrum sensing services thru this service access point.

The **measurement subsystem** and its service access point represents the device-specific implementation of the platform RF sensing and analysis functionality, usually implemented by a physical RF sensor and its associated sensing algorithm processing capacity. The standard makes no assumption on how the platform implements this service.

The **communication subsystem** summarizes the means provided by the platform to communicate between spectrum sensors and their remote clients. No assumptions are made by the standard on the implementation of the communication subsystem except the functionality of its service access point, which characterizes it as closely related to an OSI Layer 4 message transport service. Valid implementations might realize both local (i.e., via some short range physical connection) as well as remote communications (i.e., via a communication network).

The interaction of IEEE 1900.6 logical entities across service access points is realized by a set of service primitives and information elements described by the standard in the form of parameter sets in an implementation-independent way. The concise specification of these parameter sets, denoted as „sensing related information", provides the core of the IEEE 1900.6 standard. A description of the information flow between IEEE 1900.6 entities, each assuming the role of either a sensor or a client in the course of a transaction, is provided by the standard based on the exchange of such sensing related information. Herein, sensing related information basically consists of four categories: sensing information, sensing control information, sensor information, and regulatory requirements.

Sensing information denotes any measurement information that can be obtained from a spectrum sensor. As set by the IEEE Standard 1900.6 sensing information includes any related spatiotemporal state information such as position, time or confidence of acquisition. It may consist of basic measurement values such as signal/noise power levels along with the related descriptive information such as measurement bandwidth and centre frequency. Depending on a sensor's capabilities and algorithms available sensing information may also consist of more complex descriptions of the observed RF environment such as signal type, modulation type and traffic pattern of the detected remote spectrum user. In a distributed sensing scenario this sensing information may be the outcome of multiple spatially distributed RF sensing processes.

Sensing control denotes any information required to describe the status or configuration and to control or configure the data acquisition and RF sensing process of a spectrum sensor. Sensing control information is not much different from the sensing information, sharing most of the basic information elements (i.e., parameters), but is mainly used in the course of exchanging control commands. For example, RF bandwidth and centre frequency are sensing information in conjunction with the measured data obtained from a sensor but they act as sensing control information when used for tuning the spectrum sensor into a new measurement process. Depending on the sensing capabilities of a sensor, sensing control information may become more complex and descriptive (i.e., describing a sensing strategy rather than setting a single sensing parameter) as in, for example, setting the scanning scheme within a given upper and lower frequency bound using a certain sweep and sojourn time for each intermediate scan step attained.

Sensor information denotes the parameters used to describe the capabilities of a spectrum sensor. Sensor information can be requested from a spectrum sensor to learn about its properties, usually describing its limitations of operation in form of operational parameters such as frequency range, accuracy and similar objectives. In this context, a client may also obtain the sensor's absolute limits of operation by requesting the sensor's electronic data sheet prepared by the sensor manufacturer. It should be noted here that the data sheet providing sensor information is considered complementary since real operational limits and confidence achieved by a spectrum sensor very much depend on the current operating conditions as well as on the RF environment describing the current operational context.

Regulatory requirements are unique for the application area of dynamic spectrum access by cognitive radios. Regulatory requirements are expressed by the same sensing and sensing control parameters as discussed above, but they denote obligations of a spectrum sensor rather than measurement or control parameters. They may be used to control and configure a spectrum sensor but may also be used to evaluate if a sensor satisfies given demands in terms of accuracy, confidence, granularity, sensitivity or similar. Hence, there is only a fuzzy boundary between regulatory requirements expressed as a set of sensing related parameters and regulatory policies.

The IEEE Std 1900.6-2011 [P1900] provides a sound baseline for a standardized information exchange between spectrum sensors and their clients. It clearly goes beyond a mere specification of a physical communication between sensing equipment and RF context analysis, and provides a logical and architectural view to the logical entities, services and interfaces involved in a distributed spectrum sensing process. Due to technological neutrality, it will be used as a baseline standard for sensing protocol stack definition in QoSMOS. However, IEEE Std 1900.6-2011 [P1900] does not provide any information on how this should be done and how it shall be implemented.

4.2 Overview on SotA Position Context Acquisition Techniques

The radio environment context acquisition is the process used to obtain the spectrum environment for the opportunistic radio. One mechanism that has already been extensively reported in QoSMOS is spectrum sensing [D3.3]. Another 'sensing' technique that is also envisaged and seems to be preferred for TVWS applications is based on geolocation and database queries. We propose here to make a brief review of the geolocation in order to understand the advantages but also the limitations of these techniques.

Geolocation is a process used to obtain the position of the user terminal and is sometimes also referred as positioning. Positioning methods may be classified by the technique employed to derive the position of the user, these are: proximity sensing, multilateration, goniometry, dead reckoning pattern matching. All the positioning methods are based on one or multiple of these techniques. Proximity sensing is the easiest and most widespread method to obtain a position. The position is derived from the coordinates of the base station that either receives signals from a terminal on the uplink or whose signal is received by the terminal on the downlink. In currently deployed cellular systems, proximity sensing is simply the information of Cell-ID.

Multilateration analyses the range or the range difference between the terminal to position and at least three base stations (trilateration). If the positioning is based on range, the target is calculated by circular lateration, if it is based on range differences by hyperbolic lateration. One of the most common methods of multilateration is based on trilateration (three laterations) with time of arrival or time difference of arrival. Goniometry is also a method to estimate a position using the coordinates of several base stations. The method measures the angle of arrival of the signal received at the different based stations in order to derive the localization of the terminal. Triangulation is based on this technique.

Dead reckoning has been established as an abbreviation for deduced reckoning and is often referred as inertial navigation. The position of the terminal is deduced from the last known position, assuming that the direction and either velocity or travel distance of the terminal to locate is known. Dead reckoning is widely deployed for car navigation in order to maintain navigation instructions for the driver in case of temporary weak Global Positioning System (GPS) reception (which happens in urban canyon or when a car passes through a tunnel).

At last, pattern matching is based on the observation of the scene to draw conclusions on the position from these observations. One of the most popular and large scale pattern matching mechanism is WLAN fingerprinting currently used (in hybrid mode) by Google positioning API for instance.

Table 4-1: Overview of positioning methods

Positioning Method	Observation Detection	Description
Proximity Sensing	Cell-Id	Sensing for control signal
Multilateration	Range or Range Difference	Traveling time of signal Path Loss of signal Traveling time difference of signals Path loss difference of signal
Goniometry	Angle	Measure of signal angle of arrival by the base station (
Dead Reckoning	Position and Direction, Velocity and Distance	Gyroscope Accelerometer Odometer
Pattern Matching	Fingerprint	Received signal strength and signal type identification

For the various methods of positioning, it is necessary to identify the criteria that may be used for evaluating the quality of the different positioning methods. These are:

- Accuracy and precision: this criterion is usually considered as the most important quality parameter. Accuracy and precision are often interchangeable. However, accuracy usually refers to how far the estimate is located from the true position, while precision refers to the distance from the estimate to the mean of the estimates.

- Yield and consistency: yield refers to the ability of the method to estimate positions in all environments (for instance indoor or outdoor, in urban canyon and rural areas), while consistency is a measure for the stability of accuracy in different environments.
- Latency: refers to the time period between the request of a position and the delivery of the position estimate. Sometimes in positioning techniques, latency is measured by the time to first fix as position is tracked over time.
- Overhead and power consumption: refers to the cost of the method. Overhead includes extra infrastructure or signalling required for the method. Power consumption is mainly of importance at the battery powered terminal.

Out of the currently available positioning techniques, three families of technique are of particular interest as they have been widely used and tested. These are satellite positioning, cellular positioning and Wi-Fi positioning techniques.

Satellite Positioning

Satellite navigation systems have been popularized by the advances of the U.S. American Global Positioning System from the mid 1990's as positioning receivers became widely available for mass market applications. The system has been developed in the end of the 70's and has been an aid to civilian navigation worldwide since 1983. Although GPS is the most famous satellite positioning systems worldwide, other competing systems use similar principles. This is the case of the European System Galileo (currently not fully operational) or the Russian system GLONASS or the future Chinese system Compass. Some plan to propose a worldwide coverage while others have a more regional coverage, such as the Indian Regional Navigational Satellite System (IRNSS).

The GPS system is composed of a fleet of up to 32 satellites orbiting in 6 different orbital planes with an orbital period of around 12 hours. Currently 31 satellites form the so called space segment of the GPS. The operation of positioning comprises three steps: identification of satellites, range measurements and position calculations.

Two classes of errors can be distinguished for the GPS: User Equivalent Range Error (UERE) and Dilution of Precision (DOP). UERE represents the accuracy of the range measurements and is subject to a number of error sources. DOP is an indicator for an advantageous or disadvantageous geometry of satellite constellation and can be another important error source. In general, a greater angle between the satellites observed during measurements leads to higher accuracies.

Table 4-2: Example of observed GPS error budget

Error Source	Range error magnitude [m, 1σ]
Ionospheric error	7.0
Tropospheric error	0.7
Clock and ephemeris error	3.6
Receiver noise	1.5
Multipath	1.2
Total user equivalent range error	8.1
Typical horizontal DOP	2.0
Total horizontal accuracy (2σ)	32.5

Assisted GPS or A-GPS has been invented to reduce the Time To First Fix (TTFF) of the GPS (i.e.: the time the GPS receiver takes to acquire a position). The cellular network provides the almanac (orbit and status information for each satellite in the constellation) and a rough initial position of the user to speed-up the estimation of the position.

Cellular Network Positioning Technologies

Cellular Network may essentially rely on two technologies for positioning: fingerprinting [Otsas05], [Layh06] and trilateration. For GSM, the following methods have been included in the standardization: Cell identity (cell-id) and timing advance, uplink Time of Arrival (ToA), enhanced observed time difference. Cell-id is a method based on proximity sensing coupled with timing advance allows identifying a ring of potential positions with the serving base station at its centre. In GSM, a terminal is on only in connection with one base station and therefore timing advance values are not available for neighbouring base stations. No dedicated pilot signals are used for positioning. Instead, the structure of time slots and TDMA frames serve as a basis for timing measurements. Strictly speaking, the terminal observes the first arriving pulse of a predefined time slot and timestamps it. Furthermore, for circular lateration, it is required to have the terminal synchronized with the base stations, while for hyperbolic lateration the base stations must be synchronized among each other. For UMTS, Observed Time Difference of Arrival (OTDoA) is the counterpart of Enhanced Observed Time Difference (E-OTD) of GSM and is therefore based on the same principles. For the Uplink Time Difference of Arrival (U-TDoA) the hyperbolic lateration is performed by the network rather than by the mobile station.

Table 4-3: Performance characteristics of cellular positioning methods [Küppe05]

	Accuracy			Consistency	Yield
	Rural	Sub-urban	Urban		
Cell-Id	>10 km	2-10 km	50 – 1000 m	Poor	Good
E-OTD and OTDoA	50-150 m	50-250 m	50-300 m	Average	Average
U-TDoA	50-120 m	40-50 m	40-50 m	Average	Average
A-GPS	10-40 m	20-100 m	30-150 m	Good	Good

WLAN positioning

This positioning technology is used by Skyhook and Google and has become more and more popular. The technique is particularly adapted in zones where many Wi-Fi access points are available such as in cities. Two approaches coexist: Trilateration and fingerprinting [Gusta05]. For trilateration the propagation of three (or more) access points and their positions are used to find the MS. The distance between the access points and the MS is obtained through the signal strength measurement. Fingerprinting is more likely to be adapted to this type of positioning: Any wireless access point transmits information such as SSID and MAC address, and RSSI may be estimated. All the data at one certain point are stored in a vector which than acts as the fingerprint for that position. The rather large database is queried to get the position. In outdoors a distance of 15-25 meters may be attained. The main benefit of the technique is to acquire a position in a shorter time than GPS.

The level of accuracy provided by the different systems of positioning should be compared with the requirements already formulated for the TVWS scenario by FCC [FCC09] and OFCOM [OFCOM09]. FCC recommends a level of accuracy of 50 m and OFCOM of 100 m. The different positioning technologies should be able to meet these criteria. The difficulty for the context acquisition may be more on the time required to get positioning information and the yield of the technology rather than its actual level of accuracy. In conclusion, all of these methods can be used to gather the position in a QoSMOS system.

4.3 Requirements Derived from QoSMOS System Requirements

In the following we will list requirements for the protocol stack messages which are induced by the QoSMOS scenarios and the deduced QoSMOS system requirements. A detailed description of the scenarios can be found in [D1.2] whereas the system requirements are introduced in [D1.4]. We do not repeat these here.

We found 6 main functional requirements necessary for a complete description from a system point of view. These requirements are:

- Complexity
- Flexibility
- Sensor setting capability
- Sensor information distribution
- Sensor measurement results distribution
- Sensor decision results distribution

These requirements are defined in the following tables.

Req. ID:	**QPS.Comp**
Title:	Protocol Stack Complexity
Text:	The QoSMOS protocol stack shall have an appropriate complexity to serve for a cost efficient implementation.
Related QoSMOS requirements:	B.cost

Req. ID:	**QPS.Flex**
Title:	Protocol Stack Flexibility
Text:	The QoSMOS protocol stack shall be flexible so that the implementation in different terminal types is possible.
Related QoSMOS requirements:	B.term, S.coex, A.ifintra, A.ifinter, A.mrat-iw, A.flex

Req. ID:	QPS.SensSet
Title:	Sensor Setting using Protocol Stack
Text: The QoSMOS protocol stack shall be used to configure the settings of the addressed sensor entity.	
Related QoSMOS requirements:	S.freq, S.ctxinfo, S.coex, S.intf, S.prot, S.sens, S.rob, P.term

Req. ID:	QPS.SensInfo
Title:	Sensor Information
Text: The QoSMOS protocol stack shall be used to retrieve the information of the used sensor, its settings and performance.	
Related QoSMOS requirements:	S.ctxinfo, S.ctxresp, S.intf, S.sens, S.geoloc, S.rob, P.term, P.srxsens

Req. ID:	QPS.SensMeas
Title:	Sensor Measurement Results
Text: The QoSMOS protocol stack shall be used to retrieve the results of the measurements of the used sensor.	
Related QoSMOS requirements:	S.ctxinfo, S.ctxresp, S.intf, S.sens, S.rob, P.srxsens, A.geoloc

Req. ID:	QPS.SensResult
Title:	Sensor Decision Results
Text: The QoSMOS protocol stack shall be used to retrieve the results of the sensing decisions, its constraints, location and sensitivity.	
Related QoSMOS requirements:	S.ctxinfo, S.ctxresp, S.intf, S.prot, S.sens, S.geoloc, S.rob, P.lat, P.srxsens, A.geoloc

4.4 Requirements from CM-RM and CM-SM

Spectrum sensing may be exploited for different scopes at CM-RM and CM-SM. The CM-SM may use spectrum sensing to build-up or maintain the radio context, whereas the CM-RM may need spectrum sensing for incumbent detection (when applicable). The results available at the CM-RM may be exploited also by the CM-SM.

Figure 4-3 shows the block of the QoSMOS functional architecture with which the SS directly interworks. At the CM-RM, spectrum sensing is exploited for Networking domain Cognition (NC) and Terminating domain Cognition (TC) [D5.2]. The context that provided to the Spectrum ANalyser (SAN) block of the CM-SM propagates potentially down to repositories and databases through the LOCalised context (LOC) and REPositories access (REP) block groups [D6.2] [D6.3].

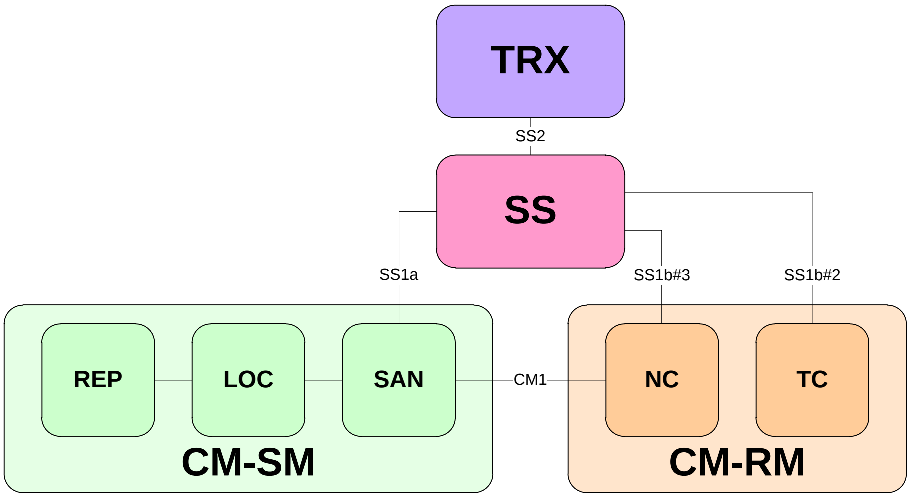

Figure 4-3: CM-RM reference model

4.4.1 Interaction with CM-RM

The detailed reference model for the CM-RM [Mange11] [Levei12] has been defined in [D5.2] and is shown in Figure 4-4 where the block SS represents the sensing devices.

The CM-RM communicates with the sensing devices (SS in Figure 4-3) both in the networking and terminating domains through the interfaces SS1b#2 and SS1b#3 as shown in Figure 4-3.

These interfaces link the SS to the blocks designated as CM-RM TC (Terminating Cognition) and CM-RM NC (Networking Cognition). These modules are in charge of gathering information on the environment in the terminating and networking domains respectively.

The interfaces have been defined in [D5.2] and are repeated for convenience here.

Table 4-4: SS1b#2 interface summary

Name:	SS1b#2		
Between	SS	and	CM-RM TC
Description:	This interface is used for exchanging spectrum sensing control information between a CM-RM TC entity and their associated spectrum sensing entities.		
Configuration of sensing measurements.		Sensing measurements result, including incumbent detection. Sensing node capabilities.	

Table 4-5: SS1b#3 interface summary

Name:	SS1b#3		
Between	SS	and	CM-RM NC
Description:	This interface is used for exchanging spectrum sensing information between a CM-RM NC entity and their associated spectrum sensing entities in case of centralised or distributed sensing.		
Configuration of sensing measurements.			Sensing measurements result, including incumbent detection. Sensing node capabilities.

In summary the requirements from the CM-RM to the SS are:

- Provision of two bidirectional interfaces SS1b#2 and SS1b#3.
- Flow in the interfaces
    - From SS to CM-RM: sensing results about physical environment
    - From CM-RM to SS: command information to request data and configure sensing
- Type of interface: periodical or asynchronous

Configuration commands may specify for a given observation interval periodic reporting or measurements (periodic mode), or request a specific measurement to performed immediately upon reception of the command and reported immediately after completion (asynchronous triggered mode).

4.4.2 Interaction with CM-SM

The reference architecture for the CM-SM has been described in [D6.2] and updated in [D6.3]. Compared to the CM-RM, the CM-SM deals with long term usage of the spectrum and the composition of the most appropriate portfolios. The required information to build the spectrum portfolios comes from the SS, the CM-RM, repository databases and external policies.

The interface between the CM-SM and SS is the SS1a, through which the CM-SM may require a fast update on the status of a given channel to update the databases. In this case a connection is established between the CM-SM and SS through asynchronous REQ/RSP (Request / Respond) message pairs triggered from the CM-SM which instructs the SS to immediately perform measurements about a specific channel and report it.

Table 4-6 gives a summary of interface communication enablers that relate CM-SM with SS, along with associated primitive names and corresponding description of the task each performs in each row.

Table 4-6: SS1a primitives and their functions

Interface:	SS1a
Flow	CM-SM↔SS
Primitive Name:	SensingMeasurement.REQ/RSP SensingResult.IND
Function:	SensingMeasurement -CM-SM requires fast sensing (energy present or absent) of measurement on a particular channel to confirm if it is no more in use and then updates its database. SensingResult Used by SS to convey SS fusion information to CM-SM directly. Can also give an indication of the total number of intending transmitters.

4.5 LTE Extension

4.5.1 Introduction

In this section, the requirements defined in [D3.2] for an extension of LTE to be used in TVWS are updated. Two main families of requirements have been defined, namely:

- requirements related to sensing measurements (i.e. how and when sensing itself is performed and controlled) and
- requirements related to sensing results report (i.e. exchange of sensing results between nodes)

In this deliverable, some existing requirements are reformulated and additional requirements have been identified, into the existing two families of requirements. Furthermore, we extend the families of requirements to three families by defining another one: requirements related to sensing performance.

4.5.2 Requirements for LTE Extension in TVWS

As specified in [D3.2], the sensing functionality integration in LTE system should have low impact on the existing LTE protocols stack. Good performance in sensing should be achieved without defining a separate stack and/or a separate radio. The cooperative sensing, which is a mean to improve the sensing performance, particularly for low Signal to Noise Ratio (SNR), should be enabled by the eNB (which serves as a master node) and some camped UEs (serving as sensing nodes). It is important to notice that for the time being, a given UE cannot be a master node as no direct connection exists between the UEs in the current LTE 3GPP specifications.

From the point of view of the protocol stack, it has been further defined three groups of requirements for LTE extension in TVWS, all related to the sensing task:

- measurements requirements,
- performance requirements, and
- reporting requirements.

As explained in Figure 4-4, a UE can be in RRC_CONNECTED or RRC_IDLE [TS 36.331] mode. When in RRC_CONNECTED mode, the possible tasks are:

- sensing, in UE Measurement Gaps (MGs), and the channels to be measured are the back-up channels (i.e., TVWS channels not used by the serving eNB) and

- classification, in case of channels in operational mode (i.e., TVWS channels used by the serving eNB).

Similar possible tasks are also for RRC_IDLE mode, but in this case the sensing and the classification will be constrained by the necessary Discontinuous Reception (DRX) used for power saving. It is important to mention that the advantage of using the RRC_IDLE mode is that MGs are no longer needed. However, new reporting requirements have to be defined for integrating RRC_IDLE mode sensing and classification.

For all of these previous described cases our assumption is that the LTE system is not using quiet period techniques (cf. Figure 4-4). One reason of this assumption is that quiet period techniques require synchronization between all the opportunistic equipment using the licensed band, which means that all the opportunistic equipment have to cease transmitting at a given time. Another reason of this assumption is that, when quiet period is used, it is difficult to have an estimation of the available sensing and classification time. Therefore, when using quiet period it is difficult to estimate the integrated sensing performance and therefore to compare it with the regulatory detection threshold. One can notice that sensing and classification performance depends on the other opportunistic equipment timings. Please note that the quiet period is different from the measurement gap as it requires the synchronization of all measurement gaps and it does not allow any transmission in the non-licensed band from any UE or eNB belonging to the opportunistic non-licensed system.

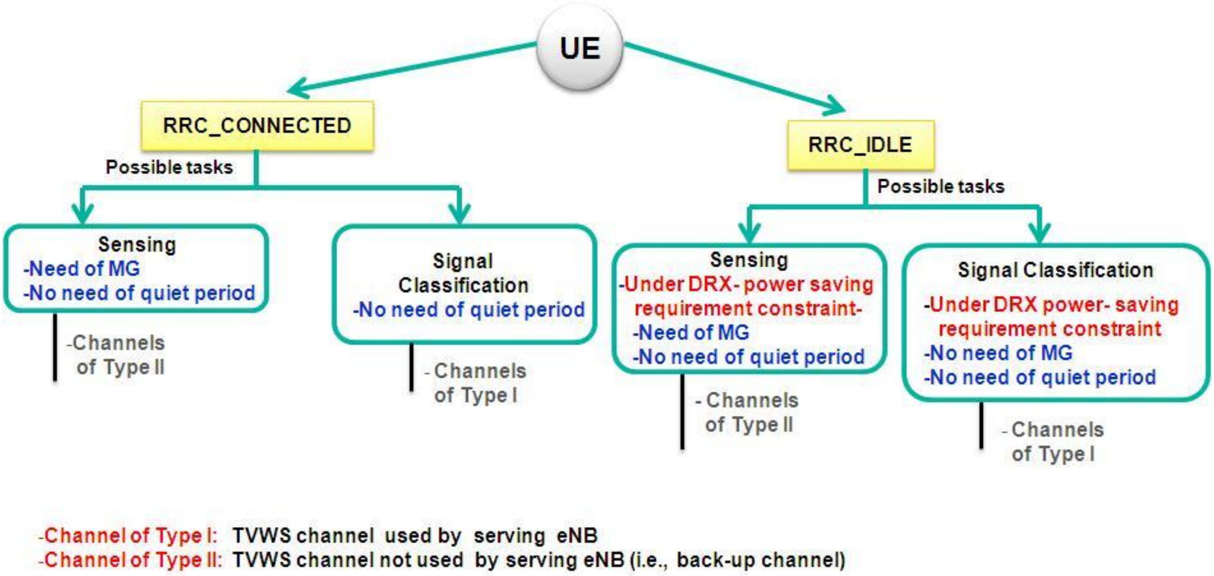

Figure 4-4: Spectrum monitoring integration in LTE

Sensing measurements requirements:

As depicted in the above Figure 4-4, depending on the RRC state of a UE, and depending on the channel to be monitored, the UE could perform either spectrum sensing or signal classification. Spectrum sensing is suitable in channels that are not used by the serving eNB, while signal classification is efficient in TV channels that are already used by the serving eNB.

- Spectrum sensing in TVWS channels not used by the serving eNB: The UEs should be able to perform spectrum sensing in a TVWS channel that is not used by the serving eNB either in RRC_CONNECTED mode or in RRC_IDLE mode under DRX power saving constraint. In RRC_CONNECTED state, the sensing is possible during MGs when there is some gap left after performing all the required LTE measurements (e.g., GSM, UMTS for inter-RAT). In RRC_IDLE state, the sensing task should be performed while meeting the DRX power saving requirements constraints.

- Signal Classification in TVWS channels used by the serving eNB: The UEs should be able to perform signal classification in a TVWS channel that is used by the serving eNB either in RRC_CONNECTED mode or in RRC_IDLE mode under DRX power saving constraint. In RRC_CONNECTED state, the signal classification is possible, without any quiet period, in any TVWS channel used by the serving eNB. In RRC_IDLE state, the signal classification is possible without any quiet period and does not need any measurement gap. However, in RRC_IDLE state, the signal classification task should meet the DRX power saving requirements constraints specified in 3GPP standardization.

4.5.2.1 Sensing Measurements Requirements

The protocol stack measurement requirements are stated in Table 4-7.

Table 4-7: Sensing measurements requirements

[QPS.LTE.Meas1]	There should not be a separate protocol stack defined for sensing measurements. Note: The LTE protocol stack is well defined by 3GPP Rel-8/9 specifications. The main specifications of interest for us are: • TS 36.331 LTE RRC [TS 36.331] • TS 36.321 LTE MAC [TS 36.321] • TS 36.304 LTE Idle Mode procedures. [TS 36.304] • TS 36.314 LTE measurements [TS 36.314] Defining a „separate" protocol stack would mean defining new specifications in addition of the documents above, thus typically defining new RRC and MAC layers for the sole purpose of sensing measurements. Instead, this requirement states that the sensing measurements should be integrated in the procedures and messages already defined in the existing specifications, or if needed by defining new procedures/messages without defining a new layer entirely.
[QPS.LTE.Meas2]	The impact of the sensing measurement functionality on the LTE stack should be minimized, while still meeting the sensing performance requirements defined in Table 4-8
[QPS.LTE.Meas3]	Both UEs and eNB may be able to perform sensing measurements. Depending on UEs context (CONNECTED/IDLE), sensing measurements should be an optional feature which the eNB is made aware of thanks to the signalling of UE capabilities.
[QPS.LTE.Meas4]	RRC_CONNECTED UEs shall be able to perform spectrum sensing in TVWS channels that are not using by the serving eNB. Such a sensing task should be performed in the measurement gaps when time remains after the UE has performed all the required LTE measurements. Therefore, the existing LTE measurement configuration (RRC messages and procedures) should be extended to support sensing configuration. This has an impact mainly on TS 36.331.

[QPS.LTE.Meas5]	RRC_CONNECTED UEs should be able to perform signal classification in TVWS channels that are used by the serving eNB without any quiet period.
[QPS.LTE.Meas6]	RRC-IDLE UEs should be able to perform sensing measurements in TVWS channels that are not used by the serving eNB, while meeting the required DRX power saving constraints. Therefore, the UE behaviour description in Idle mode should be adapted or extended. This has an impact mainly on TS 36.304.
[QPS.LTE.Meas7]	RRC-IDLE UEs should be able to perform signal classification in TVWS channels that are used by the serving eNB without any quiet period, while meeting the required DRX power saving constraints.
[QPS.LTE.Meas8]	The measurements should be performed with no quiet period. Please note that the quiet period is different from the measurement gap as it requires the synchronization of all measurement gaps and it does not allow any transmission in the non-licensed band from any UE or eNB belonging to the opportunistic non-licensed system.

4.5.2.2 Protocol Stack Performance Requirements for Sensing

The protocol stack performance requirements are stated in Table 4-8.

Table 4-8: Protocol stack performance requirements for sensing

[QPS.LTE.Perf1]	Two classes of spectrum monitoring duration should be defined: (1) The duration of the sensing that is performed before the system decides if a TVWS channel is available. This duration should be as long as possible in order to achieve reliable sensing. (2) The duration of the in-service classification that is typically much smaller than (1). What we call in-service classification is the signal classification used after a white space which has already been detected is opportunistically used by the LTE system.
[QPS.LTE.Perf2]	The sensing/classification periodicity shall be chosen such that the delay and the QoS requirements of the incumbents (DVBT, PMSE) are met. The sensing/classification periodicity is defined as the maximum time during which the LTE system could be unaware of a reappearing incumbent user and hence could harmfully interfere with it.
[QPS.LTE.Perf3]	For UEs in IDLE mode, the sensing/classification periodicity should be chosen such that the energy consumption is limited.
[QPS.LTE.Perf4]	The energy consumption of the sensing/classification reporting should be minimized.

4.5.2.3 Sensing Reporting Requirements

The sensing reporting requirements cover all the aspects related to the reporting of the sensing configuration settings and the reporting of the sensing results. These requirements are stated in Table 4-9.

Table 4-9: Sensing report requirements

[QPS.LTE.Rep1]	There should not be a separate protocol stack defined for sensing reporting. What is meant here by „separate" protocol stack is explained in [Measurement-R1] in Table 4-7.
[QPS.LTE.Rep2]	The impact of the sensing reporting functionality on the LTE stack should be minimized, while still meeting the sensing performance requirements.
[QPS.LTE.Rep3]	Only eNBs are able to aggregate sensing results in cooperative sensing schemes, i.e. UEs can only report the sensing measurements to eNBs, and not to other UEs.
[QPS.LTE.Rep4]	UEs should have the capability to prioritize the transmission of sensing results in case of incumbent user detection.
[QPS.LTE.Rep5]	UEs should have the capability to send the sensing results by the end of the scheduled sensing time.
[QPS.LTE.Rep6]	Size of sensing results should be minimized.
[QPS.LTE.Rep7]	The existing LTE measurement report (RRC messages) should be extended to support sensing results reporting.
[QPS.LTE.Rep8]	In addition of [QPS.LTE.Rep7], the existing LTE MAC Control Elements should be extended to support high priority sensing results reporting, in order to fulfil [QPS.LTE.Rep4]
[QPS.LTE.Rep9]	RRC-CONNECTED UEs should be able to report their sensing measurements (if they support the feature). So the existing LTE measurement reporting (RRC messages and procedures) should be extended to support sensing report. This has an impact mainly on TS 36.331
[QPS.LTE.Rep10]	In addition to [QPS.LTE.Rep9], RRC-IDLE UEs should be able to perform sensing report (if they support the feature). For this high-priority reporting, Idle UEs would have to temporarily get connected and thus, a new procedure should be defined for this purpose.
[QPS.LTE.Rep11]	RRC-CONNECTED UEs which have some measurement gap left, after performing all the required measurements (e.g., GMS, UMTS for inter-RAT), should be able to notify the eNBs for available measurement gap that could be used for TVWS sensing. For this signalling, a new signalling scheme has to be thought.

4.5.3 Way Forward

Based on the above requirements, the next step would be to build an integration scheme for sensing functionality in LTE protocols stack, and to find out the sensing performance under different RAN configuration schemes:

- For RRC_CONNECTED UEs, assuming that it remains some available measurement time after performing all the required LTE measurements,
- For RRC_IDLE UEs, providing reliable sensing on UEs and ensuring reliable UE power saving

4.6 Extension to IEEE 802.11

While the preceding section introduces sensing techniques into a legacy system, this subsection discusses the establishment of a reliable wireless channel that can be used to provide access to and distribute sensing and spectrum occupancy information. The channel anticipated uses IEEE 802.11 as radio link and to be able to transmit the radio environment information reliably, the link must be able to support QoS. In [D3.2] we discussed the requirements that are to be met to be able to provide QoS for the exchange of sensing and radio environment information to and between cognitive radio nodes. Main requirements include that there should be no centralized QoS control mechanisms, and any framework for QoS should implement distributed resource reservation. This resource management system should include an Adaptive Admission Control Algorithm (AACA) which will allocate dedicated resources for the information exchanges (Real Time Traffic Fractions - RTTFs). The dynamic MAC scheduler is needed to ensure the release or reallocation of resources occupied by terminated RTTFs; this will help that the bandwidth used for the exchange of information will be used more effectively.

4.6.1 Distributed Resource Reservation for 802.11

The approach defines a resource reservation scheme called EDCA (Enhanced Distributed Channel Access) which implements distributed resource reservation (EDCA/DRR). It is based on EDCA/RR (EDCA with Resource Reservation) and improves the efficiency of bandwidth utilization in IEEE 802.11e-based networks. In the EDCA/RR scheme, resource reservation is the key process that facilitates guaranteeing QoS for real-time traffic flows with strict QoS requirements. But it has to be considered that resources that have been distributed to individual QoS guaranteed flows cannot be released or utilized by other flows before these flows, occupying bandwidth in CFP (Contention free Period), completed their transmissions.

The distributed resource reservation scheme described in this chapter introduces an adaptive admission control algorithm (AACA) and a dynamic MAC scheduling mechanism. The AACA is responsible for checking whether there are RTTFs transmitting in Contention Period (CP) and recognizing their priority when a particular TXOP (Transmission Opportunity) is seen as idle. The AACA is implemented on top of the IACA (Initial Admission Control Algorithm) in order to make the ACA (Admission Control Algorithm) adaptive to the traffic behaviour. Figure 4-6 depicts the cooperative process between IACA and AACA. In general, ACAs refuse to let new QoS sensitive flows access the channel if their QoS requirements cannot be met with the “available” resources. However, the IACA has a novel approach for treating RTTFs when QoS guarantee cannot be achieved. Instead of completely rejecting these flows from accessing the channel, it lets them transmit in CP with degraded performance and the strict QoS requirements are not guaranteed for them. With the support of the AACA, QoS levels of RTTFs could be upgraded and guaranteed if they can get the available TXOPs that are left by terminated (or ending) QoS flows.

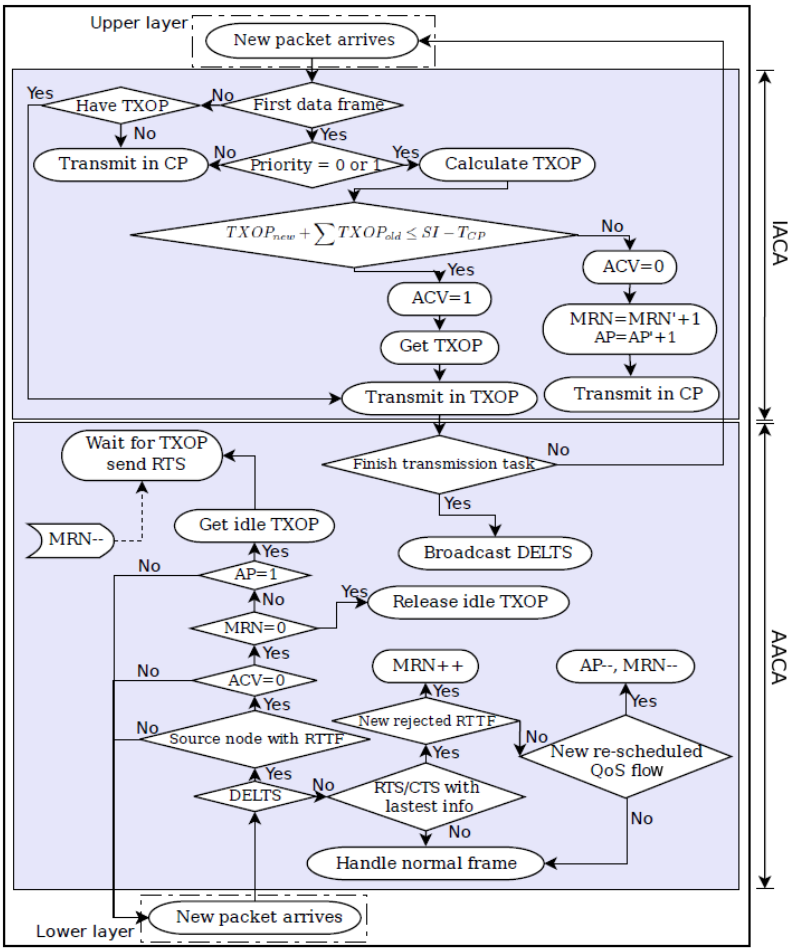

Figure 4-5: IACA and AACA Algorithms

When a QoS flow finishes its transmission task, given the condition that no RTTFs transmit in the contention period, the dynamic MAC scheduler will free up the unused resources and will then re-schedule all the flows according to current demand and requirements. If the termination of a QoS flow during contention free period happens while there are some rejected RTTFs transmitting in CP, then the dynamic MAC scheduler will re-distribute the resources to one of the RTTFs according to the decisions made by the AACA. The AACA will select the one flow that arrived first during CP and will then re-allocate the TXOP to it, if that flow still requires dedicated resources. The detailed algorithm for both distributed release process and distributed re-allocation process are described in the two subsequent sections.

4.6.2 Distributed Releasing Process

To implement the distributed re-allocating process as well as the distributed release process, three parameters are created. They include:

- ACV (Admission Control Validation): ACV is an identifier (default value is -1) set by each QoS station. If the new RTTF secures the permission of the IACA and gains the bandwidth in CFP, ACV in the corresponding station is set to 1. If the RTTF is rejected by the IACA and forced to transmit in CP, ACV is set to 0.
- APR (Arrival Priority): APR is a parameter (default value is 0) that is defined in every QoS station in order to differentiate the arrival sequence of each rejected RTTF.
- MRN (Maximum RTTF Number): MRN is a counter (default value is 0) that is allotted in each QoS station in order to record the number of RTTFs in CP.

The QoS guaranteed flows transmit data during their reserved TXOP after successfully passing the validation of IACA. If one of these traffic flows finishes data transmission, the corresponding TXOP and the reserved resources, which are no longer used, should become available to the other traffic sources. For this purpose, we utilize a control frame, called DELete Traffic Session (DELTS), in order to release the reserved resources and notify the other stations. When a QoS flow finishes its data transmission, the corresponding node broadcasts a DELTS frame that notifies the other node about the newly appeared unused (i.e. idle) resources. When a DELTS frame is received, all the active source nodes will be checked by the proposed AACA in order to figure out whether there are RTTFs transmitting in CP. The dynamic re-allocating process to distribute the idle resources will be activated if MRN becomes 0.. If the AACA finds that no RTTFs remain in CP (MRN = 0), then the corresponding TXOP and its resources will be freed up. After the releasing process ends, all the active nodes re-schedule TXOPs that there are in CFP, and they give all the residual bandwidth to CP.

4.6.3 Distributed Re-Allocating Process

As mentioned in section 4.6.2, when nodes receive a DELTS frame, each node with RTTF(s) activates their AACA in order to enable the flow with the highest priority RTTF to get the available transmission opportunities. The arrival priority of a new RTTF is checked by the AACA (in the MAC layer) of the node where the RTTF arrives. The AACA executes the Admission Control Validation (ACV) and sets the corresponding flag to “0”. A node with the APR set to “1” can directly obtain the idle bandwidth for its RTTF. When a rejected RTTF station with APR = 1 begins transmitting in contention free period, it updates the MRN (MRN new = MRN1) and then disseminates the information to other stations through the RTS (Ready To Send) and CTS (Clear To Send) frame. When other rejected nodes with RTTF(s) overhear the latest MRN from the control frame, their APR and MRN will be adopted accordingly.

4.6.4 Performance Evaluation

The effectiveness of the proposed bandwidth release process as well as the proposed bandwidth re-allocation process with the support of proposed AACA for QoS traffic flows in WLANs have been evaluated using a corresponding simulator. The assumptions and system parameters are shown in Table 4-10

Table 4-10: Simulation parameters

Parameter(units)	Value
Propagation model	Two ray ground
Transmission range(m)	250
Channel capacity(Mbps)	11
Antenna	Omni-directional
MAC protocol	IEEE 802.11e EDCA
Interface queue size(packets)	50
Data packet size(bytes)	512
Service interval(s)	0.01
Traffic application	CBR over UDP
RTTF sending rate(kb/s)	2816
NRTTF sending rate(kb/s)	2560

In the simulation scenario, all source nodes are randomly deployed within a 200m area and the sink for all the senders is deployed at the centre, this scenario can be seen as realistic in short range opportunistic access scenarios. There are 4 transmitters in the first simulation scenario 3 of them with real-time traffic flows and the fourth with a non-real-time traffic flow (NRTTF). The NRTTF flow is set to begin at 10s. After the first traffic flow (i.e. the NRTTF) begins accessing the channel, the other 3 QoS flows (i.e. RTTFs) start transmitting at 50s, 100s, 150s, respectively. All the RTTFs are allowed to get a TXOP during each SI (Service Interval) while only NRTTF transmits in CP. The 3 RTTFs stop their data transmission at 250s, 300s, and 350s, respectively. The total simulation time was set to 500s.

The other simulation parameters are summarized in Table 4-10. Figure 4-6 indicates the throughput performance for the EDCA/RR resource reservation solution. When the 3 RTTFs, which are granted to use the resources in CFP, begin their data transmission, the required bandwidth is removed from NRTTF and allocated to the RTTFs by the scheduling mechanism. Thus, a plunge of throughput for the NRTTF can be seen. However, the performance for the NRTTF does not improve, even after bandwidth reserved for QoS flows becomes unused. This attributes to the fact that no de-allocation or release process is made for the idle TXOP. Therefore, NRTTF continually utilizes the limited CP and hence its throughput performance continues at the same low value.

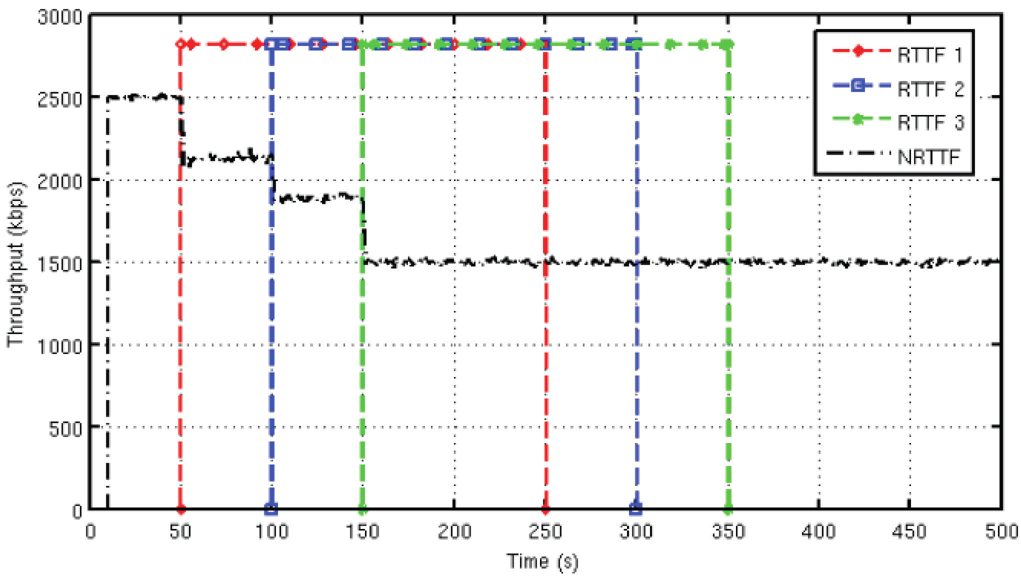

Figure 4-6: EDCA/RR

This clearly indicates the drawback of the EDCA/RR scheme. Figure 4-7 illustrates the throughput performance of the proposed EDCA/DRR scheme. It can be observed that the throughput of the NRTTF recovers as the dynamic algorithm frees up the resources that are no longer used by the QoS flows.

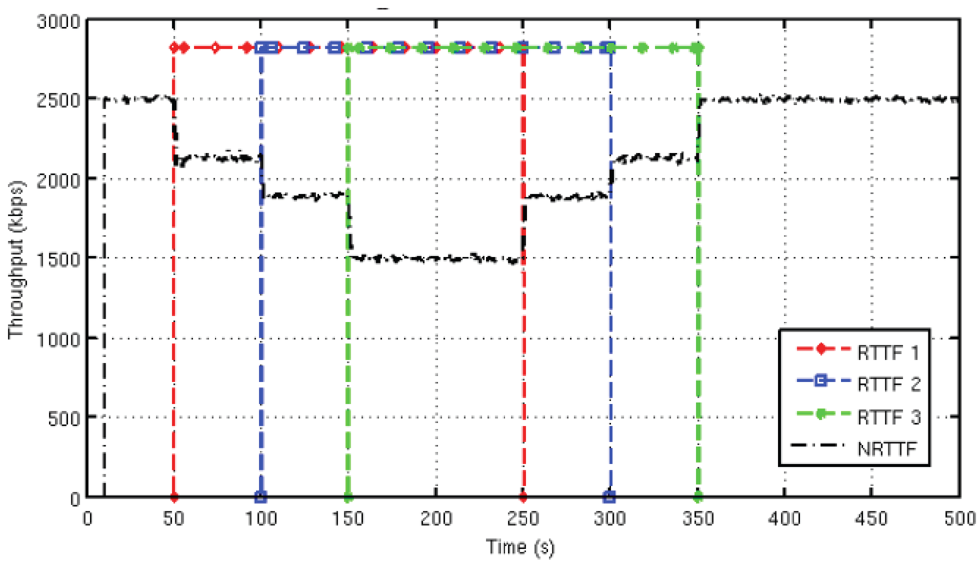

Figure 4-7: EDCA/DRR

Figure 4-8 shows the channel capacity utilization (or usage) for both EDCA/RR and EDCA/DRR. It can be seen that the efficiency of channel capacity utilization drops with EDCA/RR when the QoS flows stop transmitting as the EDCA/RR scheme fails to release the bandwidth. For instance, the curve for the EDCA/RR scheme shows that before the third QoS flow starts transmitting (i.e. t=100-150), the total capacity usage is around 7500kbps, but after the 3rd QoS flow finishes its transmission without releasing its occupied bandwidth (at t=250), the value drops to nearly 7100kbps for EDCA/RR, but stays stable for EDCA/DRR.

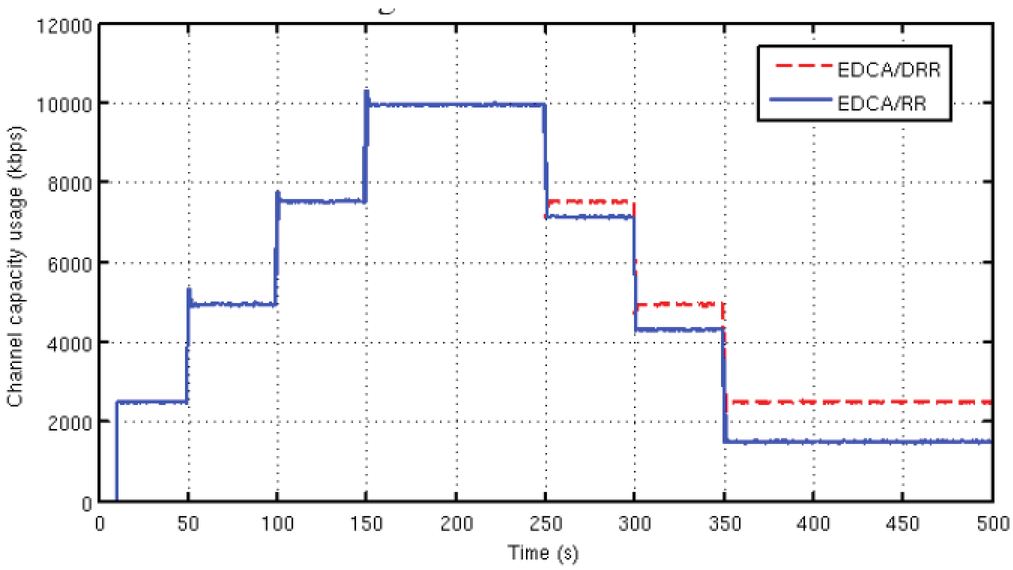

Figure 4-8: Channel Capacity/Usage

Compared with this reduced performance, it can be noted from the graph for EDCA/DRR that the total capacity utilization almost remains at the same value after the bandwidth that belongs to the 3rd QoS flow is freed up. When all the QoS flows terminate, it can be seen that the throughput of the NRTTF keeps at almost the same value as it used to be before the QoS flows started, with our proposed EDCA/DRR scheme. Table 4-11 indicates the average throughput for the EDCA/DRR scheme taken over 10 simulation runs. After a resource was reserved by a certain QoS flow, the average throughput for the non-QoS flow drops for the reason that part of its bandwidth is allocated to QoS flows. In addition, it can also be noted that the gross throughput of the entire flows increases after the time is split into SI. The reason is that data transmission during CFP has no deferral time such as AIFS and backoff in CP. Therefore, bandwidth distributed in CFP can be more efficiently utilized so that capacity utilization improvements can be achieved.

Table 4-11: Average throughput in DRR

Simulation Time	QoS Flows(kbps)	Non-QoS Flow(kbps)
10s→50s	—	2466.17
50s→100s	818.61	1748.72
100s→150s	1639.36	1252.36
150s→250s	2457.26	819.68
250s→300s	1639.75	1240.14
300s→350s	819.95	1741.01
350s→2000s	—	2466.22

The proposed MAC scheduler can dynamically release or re-schedule idle resources depending on the demand and the novel adaptive ACA is responsible for deciding whether or which RTTF can be admitted to use the idle bandwidth in CFP. Simulation results demonstrate that the proposed resource reservation scheme is effective in managing the bandwidth for RTTFs and NRTTFs, and hence helps to improve the QoS performance of IEEE 802.11e MAC protocol in a distributed manner. This means that the approach will provide clear advantages when it comes to the „guaranteed“ exchange of sending and other information needed to support opportunistic decision making in CRSs.

4.6.5 Requirements Tables

As aforementioned, requirements related to the protocols for measurements and some related to reporting sensing results are listed in Table 4-12 and Table 4-13.

Table 4-12: Sensing measurements requirements

[QPS.WiFi.Meas1]	There should not be a separate protocol stack defined for control and exchange of measurement commands and sensing information.
[QPS.WiFi.Meas2]	The impact of the sensing measurement functionality on the 802.11 stack should be minimized, while still meeting the sensing performance requirements.
[QPS.WiFi.Meas3]	Both 802.11 devices and Access Points should be able to perform sensing measurements. The sensing measurement functionality does not need to be signalled anywhere else in the radio access network.

Table 4-13: Sensing report requirements

[QPS.WiFi.Rep1]	There should not be a separate protocol stack defined for sensing reporting. (see also [QPS.WiFi.Meas1])
[QPS.WiFi.Rep2]	The impact of the sensing reporting functionality on the 802.11 stack should be minimized, while still meeting the sensing performance requirements.
[QPS.WiFi.Rep3]	All nodes (APs and devices) are able to aggregate sensing results in cooperative sensing schemes.
[QPS.WiFi.Rep4]	Devices and APs shall have the capability to prioritize the transmission of sensing results in case of primary user detection.
[QPS.WiFi.Rep5]	Size of sensing results should be minimized.

5 QoSMOS Protocol Stack Messages

5.1 Reflection of the Requirements

Before starting with the introduction of the different interfaces and the relevant messages, we want to introduce how the requirements as they have been listed in chapter 4 are reflected. This is done in the following Table 5-1. Most of the requirements are addressed. The messages themselves are described later in detail. We introduced a minimum set of additional messages as most of the messages were already incorporated in P1900.6. One of the main requirements is on the flexibility of the stack and its incorporation in different existing standards. In LTE for example, there is a main requirement stating that no separate protocol stack shall be defined for sensing information. Also, from the system point of view, flexibility is one of the main requirements which again lead to the decision not to introduce a new protocol stack but to define new messages to cover the sensing interface issues.

Table 5-1: Relationship between QoSMOS protocol stack solution and related requirements

Solution	Related QPS Requirements	Related LTE Requirements	Related 802.11 Requirements
Introduction of new protocol stack messages	QPS.Comp, QPS.Flex	[QPS.LTE.Meas1], [QPS.LTE.Rep1], [QPS.LTE.Rep7], [QPS.LTE.Rep9]	[QPS.WiFi.Meas1], [QPS.WiFi.Rep1],
Minimization of number of messages	QPS.Comp, QPS.Flex	[QPS.LTE.Meas2], [QPS.LTE.Perf4], [QPS.LTE.Rep2], [QPS.LTE.Rep6]	[QPS.WiFi.Meas2], [QPS.WiFi.Meas3], [QPS.WiFi.Rep2], [QPS.WiFi.Rep5]
Implementation independent approach	QPS.Comp, QPS.Flex	[QPS.LTE.Meas3]	[QPS.WiFi.Meas1]
Implementation of request messages	QPS.SensSet	[QPS.LTE.Meas3], [QPS.LTE.Meas4], [QPS.LTE.Meas5], [QPS.LTE.Meas6], [QPS.LTE.Meas7], [QPS.LTE.Meas8], [QPS.LTE.Perf1], [QPS.LTE.Perf2], [QPS.LTE.Perf3],	[QPS.WiFi.Meas3], [QPS.WiFi.Rep3]
Implementation of response messages	QPS.SensInfo, QPS.SensMeas, QPS.SensResult	[QPS.LTE.Rep4], [QPS.LTE.Rep5], [QPS.LTE.Rep8], [QPS.LTE.Rep10], [QPS.LTE.Rep11]	[QPS.WiFi.Rep4]

5.2 Interface Messages

As described in chapter 3.1, there are four interfaces for sensing in the QoSMOS framework. The following clauses show the information exchanged by them in detail.

In the QoSMOS project we want to use the parameters and data types as described in P1900.6-2011. In this case the last columns show the standard's equivalent parameter ID as described in P1900.6-2011, p.77. In some lines we changed or added new inputs, which are not part of P1900.6. These lines are in bold and a detailed description is given at the bottom of each table. The directions of the data are always given in the view of the sensing unit.

5.2.1 Sensing-Transceiver Interface SS2

The following Table 5-2 summarizes the data fields for the sensing-transceiver interface SS2. Most of the messages are already available in P1900.6. The new ones are marked in bold. These are the Cell ID, the Incumbent Tx ID, the Sensing type and the sensor sensitivity.

Table 5-2: Data fields of the Sensing-Transceiver Interface SS2

FIELD	SIZE and DATATYPE	DIRECTION	UNIT	P1900.6-ID
Antenna gain	int8	in	dB	308.7
Antenna height	uint8	in	0.1 m	308.8
Antenna polarization	uint8	in	POLAR_H, POLAR_V, POLAR_RC, POLAR_LC	308.9
Bandwidth (start/stop)	2 x uint8	in/out	Hz	101
Beam pointing	uint16	in	°	308.4
Calibration data	string	in		308.10
Cell ID	**uint32**	**in/out**	**-**	**new**
Dynamic range	uint8	in	dB	308.13
Frequency	uint32	in/out	Hz	001
Incumbent Tx ID	**uint32**	**in**	**-**	**new**
Phase noise	int8	in	dBc/Hz	308.18
Power	fixed-point	in	dBm	007
Sensing timing	int32/fixed-point	in/out	sec/µs	102
Sensing type	**uint8**	**in/out**	**SSL, SSC, SSD, WHITE_SPACE_SENS, INTERFERENCE_MON**	**new**
Sensor location absolute	3 x int32	in	m/10^{-6}°/10^{-6}° (elev/lat/long)	301
Sensor location relative	3 x int32	in	m/10^{-6}°/10^{-6}° (elev/lat/long)	302
Sensor sensitivity	**int16**	**in/out**	**dBm/Hz**	**new**

New/changed fields compared to P1900.6-2011:

- **Cell ID:** The Cell ID is an ID to recognize the specified pilot channel of the opportunistic BS or AP.
- **Sensing type:** The Sensing type indicates if white space sensing or interference monitoring is or should be used.
- **Sensor sensitivity:** The field „Sensor sensitivity“ gives the sensitivity of the used sensor.
- **Incumbent Tx ID:** The Incumbent TX ID is a transmitter ID to recognize which signals should be measured.

5.2.2 Sensing-Resource Manager/Spectrum Manager Interface SS1

The following Table 5-3 summarizes the data fields for the sensing-RM/SM interface SS1. Most of the messages are already available in P1900.6. The new ones are marked in bold. These are the Cell ID, the Probability of channel occupancy, the Sensing results delivery latency, the Sensing type, the Spectrum sensing decision and the Target PFA.

Table 5-3: Data fields of the Sensing-Resource Manager/Spectrum Manager Interface SS1

FIELD	SIZE and DATATYPE	DIRECTION	UNIT	P1900.6-ID
Antenna gain	int8	in	dB	308.7
Antenna height	uint8	out	0.1 m	308.8
Bandwidth (start/stop)	2 x uint8	out	Hz	101
Cell ID	**uint32**	**in/out**	**-**	**new**
Client Priority Flag	uint8	in/out	priority level	108
Confidence level	float	in/out	-	309.0
Frequency	uint32	in/out	Hz	001
Probability of channel occupancy	**uint8**	**out**	**%**	**new**
Received power	fixed-point	out	dBm	007
Sensing duration (s/µs)	2 x uint8	in/out	sec/µs	102
Sensing periodicity	int32/fixed-point	in/out	sec/µs	104
Sensing results delivery latency	**uint32**	**in/out**	**µs**	**new**
Sensing type	**uint8**	**in**	**SSL, SSC, SSD, WHITE_SPACE_SENS, INTERFERENCE_MON**	**new**
Sensor ID	string	out	-	306

FIELD	SIZE and DATATYPE	DIRECTION	UNIT	P1900.6-ID
Sensor location absolute	3 x int32	out	m/10^{-6}°/10^{-6}° (elev/lat/long)	301
Sensor location relative	3 x int32	out	m/10-6°/10-6°(elev/lat/long)	302
Spectrum sensing decisions	bool/uint8	out	EXIST, NON_EXIST	modified
Target PFA	uint8	in	%	new

New/changed fields compared to P1900.6-2011:

- **Cell ID:** see 5.2.1
- **Sensing type:** see 5.2.1
- **Target PFA:** Control the target probability of a false alarm (PFA) in per cent.
- **Spectrum sensing decision:** The field „Spectrum Sensing decision" conveys the decision, if the channel is occupied or not. Against the P1900.6 definition this field contains only a Boolean value.
- **Probability of channel occupancy:** This value gives the probability of an occupied channel in per cent.
- **Sensing results delivery latency:** The sensing result delivery latency includes the sensing duration, the exchange of commands and results (including to /from all involved remote sensors, if applicable), the processing of the decision (e.g., at the centre when applicable), and the distribution of the decision to the requesting entity.

5.2.3 Spectrum Sensing Management-Spectrum Sensing Sensor Control Interface SS0

The following Table 5-4 summarizes the data fields for the SS MGT – SS SCTRL interface SS0. Most of the messages are already available in P1900.6. The new ones are marked in bold. These are the Cell ID, the Detection sensitivity, the Incumbent Tx ID and the Spectrum sensing decision.

Table 5-4: Data fields of the Spectrum Sensing Management-Spectrum Sensing Sensor Control Interface SS0

FIELD	SIZE	UNIT	P1900.6-ID
Cell ID	**uint32**	**-**	**new**
Detection sensitivity	**uint8**	**dBm**	**new**
Incumbent Tx ID	**uint32**	**-**	**new**
Received power	fixed-point	dBm	007
Sensing periodicity	uint32	sec/µs	104
Sensor ID	string	-	306
Sensor location absolute (elev)	3 x int32	m/10^{-6}°/10^{-6}°	301
Sensor location relative (elev)	3 x int32	m/10^{-6}°/10^{-6}°	302

FIELD	SIZE	UNIT	P1900.6-ID
Spectrum sensing decisions	**bool/uint8**	**EXIST, NON_EXIST**	**modified**

This interface does also exist between two sensing entities!

New/changed fields compared to P1900.6-2011:

- **Detection sensitivity:** The detection sensitivity is the lowest incumbent's energy that the cognitive devices must be able to detect in order to be allowed to operate in an area or a frequency band.
- **Spectrum sensing decisions:** see 5.2.2
- **Cell ID:** see 5.2.1
- **Incumbent Tx ID:** see 5.2.1

5.3 Classification of the QoSMOS Data Fields

The following Table 5-5 shows a classification of the message fields. This can later be used as a structure for an implementation of a QoSMOS protocol stack. Column 2 gives the element name, the third column gives the equivalent variable type and size and the last column shows the related QoSMOS system requirements as introduced in [D1.4].

Table 5-5: Structure to describe the data fields needed by QoSMOS

	Message field	Size	Related System Requirements
SensorInfo	QoSMOSProtocolStack.SensorInfo.DynamicRange	uint8	S.ctxinfo
	QoSMOSProtocolStack.SensorInfo.Type	uint8	S.intf, S.ctxinfo, S.ctxinfo
	QoSMOSProtocolStack.SensorInfo.CalData	string	S.ctxinfo
	QoSMOSProtocolStack.SensorInfo.PhaseNoise	int8	S.ctxinfo
	QoSMOSProtocolStack.SensorInfo.Sensitivity	int16	P.srxsens, S.ctxresp, S.ctxinfo
	QoSMOSProtocolStack.SensorInfo.Method	uint8	S.ctxinfo, S.rob
	QoSMOSProtocolStack.SensorInfo.Antenna.Gain	int8	S.ctxinfo, P.srxsens
	QoSMOSProtocolStack.SensorInfo.Antenna.Pol	uint8	S.ctxinfo
	QoSMOSProtocolStack.SensorInfo.Antenna.Height	uint8	S.geoloc, S.ctxinfo
	QoSMOSProtocolStack.SensorInfo.Antenna.BeamPointing	uint16	S.ctxinfo
SensorSet	QoSMOSProtocolStack.SensorSet.Freq	uint32	S.freq, S.prot, S.ctxinfo, S.ctxresp, S.sens, S.rob
	QoSMOSProtocolStack.SensorSet.Bandwidth.Start	uint8	S.freq, S.prot,

	Message field	Size	Related System Requirements
			S.ctxinfo, S.ctxresp, S.sens, S.rob
	QoSMOSProtocolStack.SensorSet.Bandwidth.Stop	uint8	S.freq, S.prot, S.ctxinfo, S.ctxresp, S.sens, S.rob
	QoSMOSProtocolStack.SensorSet.Timing	int32/fixed-point	P.lat, S.ctxresp, S.sens
	QoSMOSProtocolStack.SensorSet.Periodicity	int32/fixed-point	S.coex, S.ctxresp, S.sens
	QoSMOSProtocolStack.SensorSet.SensorID	string	S.ctxinfo, S.coex, S.ctxresp, S.sens
Measurement	QoSMOSProtocolStack.Measurement.Power	fixed-point	S.ulay, S.pwr, S.prot
	QoSMOSProtocolStack.Measurement.Freq	uint32	S.freq, S.prot
	QoSMOSProtocolStack.Measurement.Bandwidth.Start	uint8	S.freq, S.prot
	QoSMOSProtocolStack.Measurement.Bandwidth.Stop	uint8	S.freq, S.prot
	QoSMOSProtocolStack.Measurement.LocationAbs.Elev	int32	S.geoloc, S.ulay, S.prot
	QoSMOSProtocolStack.Measurement.LocationAbs.Lat	int32	S.geoloc, S.ulay, S.prot
	QoSMOSProtocolStack.Measurement.LocationAbs.Long	int32	S.geoloc, S.ulay, S.prot
	QoSMOSProtocolStack.Measurement.LocationRel.Elev	int32	S.geoloc, S.ulay, S.prot
	QoSMOSProtocolStack.Measurement.LocationRel.Lat	int32	S.geoloc, S.ulay, S.prot
	QoSMOSProtocolStack.Measurement.LocationRel.Long	int32	S.geoloc, S.ulay, S.prot
	QoSMOSProtocolStack.Measurement.Incumbent_Tx_ID	uint32	S.geoloc, S.ulay, S.prot
SensingResult	QoSMOSProtocolStack.SensingResult.Decision	bool	S.intf, S.sens, S.rob
	QoSMOSProtocolStack.SensingResult.Periodicity	uint32	S.ctxresp, S.intf
	QoSMOSProtocolStack.SensingResult.Sensitivity	uint8	P.srxsens, S.sens, S.ctxresp, S.intf,

Message field	Size	Related System Requirements
		S.rob
QoSMOSProtocolStack.SensingResult.Latency	uint32	S.ctxinfo, S.ctxresp, S.rob, P.lat
QoSMOSProtocolStack.SensingResult.Reliability	uint8	S.ctxinfo, S.ctxresp, S.rob, P.lat
QoSMOSProtocolStack.SensingResult.LocationAbs.Elev	int32	S.geoloc, A.geoloc
QoSMOSProtocolStack.SensingResult.LocationAbs.Lat	int32	S.geoloc, A.geoloc
QoSMOSProtocolStack.SensingResult.LocationAbs.Long	int32	S.geoloc, A.geoloc
QoSMOSProtocolStack.SensingResult.LocationRel.Elev	int32	S.geoloc, A.geoloc
QoSMOSProtocolStack.SensingResult.LocationRel.Lat	int32	S.geoloc, A.geoloc
QoSMOSProtocolStack.SensingResult.LocationRel.Long	int32	S.geoloc, A.geoloc
QoSMOSProtocolStack.SensingResult.Power	fixed-point	S.pwr, S.intf, S.prot, P.srxsens
QoSMOSProtocolStack.SensingResult.CellID	uint32	S.ctxinfo, S.sens
QoSMOSProtocolStack.SensingResult.Incumbent_Tx_ID	uint32	S.ctxinfo
QoSMOSProtocolStack.SensingResult.SensorID	string	S.ctxinfo, S.coex, S.ctxresp, S.sens

Defined QoSMOS messages compared to P1900.6

Compared to [P1900] both protocol stack message definitions have the *sensing information* in common but here there is an additional *measurement* message defined. The QoSMOS' *SensorSet* message is comparable to the *sensing control information* and *control commands* structures. The *sensor information* is part of the *SensingResult* in this project.

6 Appendix

Table 6-1: Primitives involved in interference monitoring

Primitives	Source	Destination	Delivered Information	Description
SS1a_SensorInformation.IND	SS MGT	CM-SM	Sensor information{ Sensor location absolute (elev), Sensor location absolute (lat), Sensor location absolute (long), Sensor ID, Sensor antenna height, Sensor antenna gain (if not omni-directional)}	Notify the local CM-SM about the sensor's information.
SM0_SensorInformation.IND	CM-SM	CM-SM	Sensor information	Forward the sensor's information to the CM-SM in the CN.
SM1a_SensorInformation.IND	CM-SM	PF	Sensor information	Register the sensor's information.
SM0_InterferenceMonitoring.REQ	CM-SM	CM-SM	Operating transmit power Channel ID	Request the master CM-SM for initiating interference monitoring.
SM1b_SensorInformation.REQ	CM-SM	PF		Request the PF about the sensor information.
SM1b_SensorInformation.RSP	PF	CM-SM	Sensor information	Respond to the CM-SM about the sensor information.
SM1a_IncumbentInformation.REQ	CM-SM	REG		Request the REG about the incumbent system information.
SM1a_IncumbentInformation.RSP	REG	CM-SM	Incumbent system information	Respond to the CM-SM about incumbent system information.
SM0_SensingMeasurement.REQ	CM-SM	CM-SM	Sensing information{ Channel ID (to specify centre frequency and bandwidth), Cell ID (or Tx ID to recognize specified pilot channel of the Opportunistic Tx), Incumbent Tx ID (to recognize which signals to be measured), Sensing timing and duration, Sensing type (WHITE_SPACE_SENS or INTERFERENCE_MON) }	Request the monitoring node to perform measurements.

Primitives	Source	Destination	Delivered Information	Description
SS1a_SensingMeasurement.REQ	CM-SM	SS MGT	Sensing information	Request the sensor to perform measurements.
SS0_SensingMeasurement.REQ	SS MGT	SS SCTRL	Sensing information	Forward the measurement request to SS SCTRL.
SS2_SensingMeasurement.REQ	SS SCTRL	TRX	Channel ID, Sensing timing and durations	Forward the measurement request to the actual transceiver.
SS2_SensingMeasurement.RSP	TRX	SS SCTRL	Received baseband signals Sensing information	Report the received signals to SS SCTRL.

SS0_SensingMeasurement.RSP	SS SCTRL	SS MGT	Interference measurement results{
			Received power,
			Channel ID,
			Cell ID}
			Incumbent measurement results{
			Received power,
			Channel ID
			Incumbent Tx ID}
			Sensor ID
				Report the interference measurement results and incumbent measurement results calculated by SS SCTRL.

SS1a_SensingMesurementReport.RSP	SS MGT	CM-SM	Interference measurement results{ Received power (or the binary decision to determine whether the interference exceeds the threshold or not), Channel ID, Cell ID} Incumbent measurement results Sensor ID	Report the measurement results from the sensor.
SM0_SensingMesurement.RSP	CM-SM	CM-SM	Interference measurement results Incumbent measurement results Sensor ID	Inform the master CM-SM about the measurement results.
SM0_TxParamUpdate.REQ	CM-SM	CM-SM	Allowable transmit power Channel ID	Request the operating node CM-SM to update allowable transmit power.
CM1_TxParamUpdate.REQ	CM-SM	CM-RM	Allowable transmit power Channel ID	Request the operating node CM-RM to update allowable transmit power.

Primitives	Source	Destination	Delivered Information	Description
CM1_TxParamUpdate.RSP	CM-RM	CM-SM	Operating transmit power Channel ID	Report operating parameters to CM-SM.
SM0_TxParamUpdate.RSP	CM-SM	CM-SM	Operating transmit power Channel ID	Forward the report of operating parameters to CM-SM in core network.
SM1b_PortfolioUpdate.REQ	CM-SM	PF	Operating transmit power Channel ID STx ID	Request the PF to record the updates made in the operating node.
SM1b_PortfolioUpdate.CNF	PF	CM-SM		Acknowledge to the CM-SM that the PF updated accordingly.

7 References

[D1.2] R. MacKenzie; P.-H. Lehne; U. Celentano; M. Ariyoshi; B. Cendón; A. Medela; “QoSMOS Consolidated Scenarios”, QOSMOS deliverable D1.2, Dec 2010

[D1.4] P.-H. Lehne, U. Celentano, J. Lehtomäki, D. Noguet, R. Datta, P. Delahaye, R. Wansch, V. Berg, P. Grønsund, “QoSMOS consolidated system requirements”, QOSMOS deliverable D1.4, May 2011

[D2.2] S. Leveil, C. Le Martret; O. Grøndalen; B. Bochow; C. Rosik, V. Mérat; B. Cendón, J. Herrero, A. Medela; U. Celentano; R. Datta; F. Noack, C. Lange, J. Gebert; K. Moessner; H. Sugahara, K. Muraoka, M. Ariyoshi, “System architecture options for the QoSMOS system“, QoSMOS project deliverable D2.2, Dec 2010

[D2.3] G. Mange; P. Horváth; V. Berg; B. Bochow; R. Robles; M. Ariyoshi; C. Rosik; O. Grøndalen, P.-H. Lehne; J. Rico, A. Medela; R. Data; U. Celentano, “System specification and evaluation criteria“, QoSMOS project deliverable D2.3, Nov 2011

[D3.2] R. Wansch; U. Celentano, J. Lehtomäki, J. Vartiainen; F. Kemeth, M. Schühler, K. Arshad, X. Yu, P. Navaratnam, K. Moessner; M. Gautier; M. Ariyoshi, K. Muraoka; P. Delahaye; L. Gonçalves, “Reference protocol stack for QoSMOS radio environment mapping and sensing“, QoSMOS project deliverable D3.2, Oct 2010

[D3.3] D. Depierree; K. Muraoka; H. Sugahara; M. Ariyoshi; D. Depierre; M. Gautier; D. Noguet, J. Vartiainen; J. Lehtomäki; K. Arshad; D. Panaitopol; L. Gonçalves; A. Gameiro; “Radio Context Acquisition algorithms – Preliminary version”, QoSMOS project deliverable D3.3, Feb 2011

[D5.2] G. Mange, P. Horváth, R. Mac Kenzie, K. Briggs, M. Fitch, C. Rosik, S. Leveil, C. Le Martret, R. Massin, P. Fouillot, A. Sanz, B. Cendón, A. Medela, J. Rico, K. Arshad, T. Guo, U. Celentano, “Final framework description, preliminary cognitive manager structure and first mechanisms for QoS support“, QoSMOS project deliverable D5.2, 13 Jul 2011.

[D6.2] F. Noack, C. Lange; S. Kawade; B. Bochow; A. Gameiro; H. Sugahara, K. Muraoka, T. Nakamura, M. Ariyoshi, P. Grønsund; K. Moessner; U. Celentano, J. Vartiainen, J. Lehtomäki, “Description of context filtering, aggregation and communication functions of the spectrum management framework”, QoSMOS project deliverable D6.2, Apr 2011

[D6.3] I. Karla, F. Noack, C. Lange; A. Gameiro, A. Sousa, R. Samano; U. Celentano, J. Lehtomäki, J. Vartiainen; M. Ariyoshi, K. Muraoka, T. Nakamura, H. Sugahara; Y. Ko, K. Moessner; P. Grønsund; P. Bakki, J. Bitó, L. Csurgai-Horváth; B. Bochow, “Initial description of cognitive and opportunistic functions of the spectrum management framework", QOSMOS deliverable D6.3 , Oct 2011

[D7.2] B. Cendón, A. Medela, J. Rico, J. Duplicy, D. Tandur, D. Noguet, V. Berg, P. Delahaye, B. Bochow, C. Ribeiro, J. Quaresma, M. Schühler, M. Tessema, R. MacKenzie, K. Briggs, "Platform Architecture Definition (2/2)", QoSMOS project deliverable D7.2, Dec 2011

[Celen11] U. Celentano, B. Bochow, C. Lange, F. Noack, J. Herrero, B. Cendón, O. Grøndalen, V. Mérat, C. Rosik, "Flexible architecture for spectrum and resource management in the whitespace", *Proc. Int. Symp. Wireless Personal Multimedia Commun.* (WPMC), Brest, France, 3-7 Oct 2011.

[Gusta05] F. Gustafsson and F. Gunnarsson, "Mobile Positioning Using Wireless Networks: Possibilities and Fundamental Limitations Based on Available Wireless Network Measurements", IEEE Signal Processing Magazine, Jul 2005

[Küppe05] A. Küpper, Location-Based Services: Fundamentals and Operation, Wiley 2005

[Layh06] M. Layh, U. Reiser, D. Zimmermann, F. Landstorfer "Positioning of Mobile Terminals based on Feature Extraction from Channel Impulse Responses" IEEE Vehicular Technology Conference-Spring 2006

[Levei12] S. Leveil, C. J. Le Martret, H. Anouar; K. Arshad, T. Zahir; J. Bito U. Celentano; G. Mange; J. Rico, A. Medela, "Resource management of centrally controlled cognitive radio networks", *Proc. Future Network & Mobile Summit* (FuNeMS), Berlin, Germany, 4-6 Jun 2012

[MacKe11] R. MacKenzie, P.-H. Lehne, U. Celentano, "Identifying scenarios with high potential for future cognitive radio networks", *Proc. Future Network & Mobile Summit* (FuNeMS), Warszaw, Poland, 15-17 Jun 2011

[Mange11] G. Mange, C. Rosik, S. Leveil, U. Celentano, O. Durowoju, K. Arshad, "Cognitive resource management for QoS support in mobile opportunistic communications", *Proc. Future Network & Mobile Summit* (FuNeMS), Warszaw, Poland, 15-17 Jun 2011.

[Moess11] K. Moessner, H. Harada, C. Sun, Y.D. Alemseged, H. Nguyen Tran , D. Noguet, R. Sawai, N. Sato, " Spectrum sensing for cognitive radio systems: technical aspects and standardization activities of the IEEE P1900.6 working group", IEEE Communication Magazine, Vol. 18, pp30-37, Feb 2011

[Murao11] K. Muraoka, H. Sugahara, M. Ariyoshi, "Monitoring-based spectrum management for expanding opportunities of white space utilization," Proc. IEEE International Symposium on New Frontiers in Dynamic

Spectrum Access Network (DySPAN), May 2011

[Murro11] M. Murroni, R.V. Prasad, P. Marques, B. Bochow, , D. Noguet, C. Sun, K. Moessner, H. Harada, „IEEE 1900.6: spectrum sensing interfaces and data structures for dynamic spectrum access and other advanced radio communication systems standard: technical aspects and future outlook", IEEE Communication Magazine, Vol. 49, pp118-127, Dec 2011

[Otsas05] V. Otsason, A. Varshavsky, A. LaMarca, and E. de Lara. "Accurate GSM indoor localization". In the Seventh International Conference on Ubiquitous Computing (UbiComp 2005), Sep 2005

[P1900] K. Moessner, H. Nguyen Tran, C. Sun, B. Bochow, D. Swain, Y. D. Alemseged, M. Ariyoshi, S. Aust, H. Harada, O. Holland, T. Ito, P. Marques, M. Murroni, D. Noguet, S. Pollin, V. Prasad, N. Sato, R. Sawai, A. Yamaguchi, "IEEE Standard for Spectrum Sensing Interfaces and Data Structures for Dynamic Spectrum Access and Other Advanced Radio Communication Systems", IEEE Std 1900.6™-2011, April 2011

[FCC09] FCC. "Unlicensed Operation in the TV Broadcast Bands, Final Rules [online] URL: http://edocket.access.gpo.gov/2009/pdf/E9-3279.pdf"

[OFCOM09]. OFCOM. "Digital dividend: cognitive access Consultation on licence-exempting cognitive devices using interleaved spectrum", May 2009

[TS 36.331] 3GPP TS 36.331; 3rd Generation Partnership Project; Technical Specification Group Radio Access Network; Evolved Universal Terrestrial Radio Access (E-UTRA); Radio Resource Control (RRC); Protocol specification (Release 10)

[TS 36.321] 3GPP TS 36.321; 3rd Generation Partnership Project; Technical Specification Group Radio Access Network; Evolved Universal Terrestrial Radio Access (E-UTRA); Medium Access Control (MAC) protocol specification (Release 10)

[TS 36.304] 3GPP TS 36.304; 3rd Generation Partnership Project; Technical Specification Group Radio Access Network; Evolved Universal Terrestrial Radio Access (E-UTRA); User Equipment (UE) procedures in idle mode (Release 10)

[TS 36.314] 3GPP TS 36.314; 3rd Generation Partnership Project; Technical Specification Group Radio Access Network; Evolved Universal Terrestrial Radio Access (E-UTRA); Layer 2 – Measurements (Release 10)