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Cognitive Radio Standardization-initiative: from FP7 research to global standards

D2.5
Position paper on FP7 research directions in CR and the European standardization priorities – final version

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Abstract:
This position paper outlines the research directions that have been followed in past FP7 research projects and their mapping to standardisation efforts that have set out to develop standards for CR and DSA technologies. It also provides an overview of how spectrum policy is evolving, along with the further maturing of the technologies, and then identifies areas in standardisation that need additional attention and where there are significant gaps that are still need to closed before the full potential of CR/DSA can be exploited.

Keyword list: Cognitive Radio Systems, White Spaces, Dynamic Spectrum Access

Executive Summary

Since the first European projects on dynamic spectrum access (FP4 DRiVE and FP5 OverDRiVE) the spectrum regulation landscape has changed dramatically. Moving from the classical command and control regime towards a more flexible approach that now even allows, in some cases, dynamic sharing and dynamic access. Nevertheless, there are still areas that need further relaxation to be able to reach the full potential of what cognitive radio (CR) and dynamic spectrum access (DSA) technologies have to offer.

This position paper outlines the research directions that have been followed in past FP7 research projects and their mapping to standardisation efforts that have set out to develop standards for CR and DSA technologies. It also provides an overview of how spectrum policy is evolving, along with the further maturing of the technologies, and then identifies areas in standardisation that need additional attention and where there are significant gaps that are still need to closed before the full potential of CR/DSA can be exploited.

The paper provides an update of the ETSI and IEEE standardisation efforts towards provision of standards for CR technology. The ETSI RRS (Reconfigurable Radio Systems) continues working on the identification of the main systems aspects and cognitive functionalities that need to be captured by standards, it also emphasises the specification of enhanced Licensed Shared Access (LSA), while the work on a Reconfigurable Radio Frequency Interface (RRFI) aims towards developing a European Standard over the next couple of years. On security and regulation related work, the dynamic declaration of conformity TR is being revised and the requirements for dynamic re-certification need to be defined. IEEE activities in the 802.19.1, IEEE 802.11af, and IEEE 802.22a b are currently under sponsor ballot or have been completed, while IEEE 1900.6 and 1900.7 invite contributions as they are currently active looking into a spectrum data base related amendment, or is open for proposals for future directions of the group, respectively.

In the third section, the paper gives a brief update on the CR/spectrum sharing research directions pursued in FP7 and H2020 projects looking in particular at dynamic sharing for LSA, sharing of satellite bands, the impact and need of control interfaces and the directions currently pursued in the 5G public private partnership. Spectrum Sharing for LSA is being pursued by the ADEL project which proposes the introduction of collaborative spectrum-sensing networks, a spectrum-sensing reasoning module, and details/improves the operation of the LSA controller. Satellite bands and their potential for a more flexible use using CR technology are investigated in the CORASAT project, this has already led to input to a ETSI technical report on “Cognitive radio techniques for Satellite Communications operating in Ka band”, additional work is being pursued in the SCREEN project which aims towards the same targets as CORASAT did, but targets the S band rather than the Ka band considered in CORASAT. Control interfaces that abstract hardware specific instructions and allows full, vendor independent radio control are being investigated by the WISHFUL project, the work is aiming towards the ETSI RRS working group on the Reconfigurable Radio Equipment Architecture. Finally, the 5G PPP and associated projects look in particular into how dynamic spectrum sharing models can be applied in a 5G networks context.

Spectrum policy has evolved and continues to do so, section 4 explains the current view and directions of regulation, including the conclusion that *“a sustainable way to satisfy spectrum demand in the medium and long term is to invest more time and resources in identifying and developing more sophisticated spectrum sharing concepts.”* And at the basis of this are technologies including LSA, geo-location spectrum databases, cell-densification and increased spectrum re-use and sharing.

The changes are driven by the movement towards a single digital market is another driver that supports the push towards a more competitive approach to spectrum access and dynamic use.

This affects equipment certification as well as spectrum regulation. For equipment conformity, the traditional R&TTE Directive, which governed equipment certification in the European market, has been updated to mirror the developments that reconfigurable radio systems have brought along. The new directive contains now provisions on conformity of Software Defined and Cognitive Radios. Concerning spectrum regulation and allocation for a 5G system, the strategic plan of the CEPT sees the identification and harmonization of frequencies for 5G as one of its top priorities, this affects bands below 6GHz in particular, but recognizes that the traditional bands will not be sufficient to deliver the headline KPIs that are listed for 5G systems.

Finally, section 5 discusses the standardisation priorities that need to be met over the foreseeable future including CR/DSA security, joint layer optimisation, LSA and LAA as well as short-range device access and finally the potential of sharing military bands. On the security issues the threats have yet to be properly investigated and solutions to overcome those same threats have to be developed. Joint optimization of PHY and MAC has been already looked at and has led to interesting findings, including the realisation that a 2MHz profile is of particular interest because it enables a very flexible channel allocation where several fragments are bounded, would they be adjacent or not. This can be exploited at the MAC to enable highly flexible allocation schemes to cope with a huge set of spectrum profiles and/or QoS environment.

Activities on LSA and LAA look in particular at the structural (architecture) issues as well as, in case of LAA at the co-existence an sharing of resources in the unlicensed bands, in particular the co-existence of LTE-U and WiFi is being researched and much work has still to be pursued. Within 3GPP, there is a view that unlicensed spectrum access is regarded as a key part of 5G with many envisioning a unified approach for licensed, shared and unlicensed spectrum. The 3GPP and IEEE work on coexistence for LAA and Wi-Fi to fairly share unlicensed spectrum.

CR enabled short range devices and Low Throughput Networks are also of great interest to both research and business communities, with the emergence of companies like Sigfox, or approaches like LORA or Neul's weightless provide viable approaches for IoT applications, however the whole area of spectrum sharing for IoT networks remains largely underrepresented.

Sharing of military bands starts to become more of a possibility, supported by an EC mandate, there is the potential for future relaxation and therefore this remains an open research area.

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List of Abbreviations

BSS	Broadcast Satellite Service
CEPT	Conference of European Postal and Telecommunications Administration
CR	Cognitive Radio
CRS	Cognitive Radio System
CRS	Cognitive Radio Standardization – cluster projects
D2D	Device-to-Device
DSA	Dynamic Spectrum Access
DVB-T	Digital Video Broadcast – Terrestrial
ECC	Electronic Communications Committee
ERM	Electromagnetic compatibility and Radio spectrum Matters
ETSI	European Telecommunication Standards Institute
EU	European Union
FSS	Fixed Satellite Service
GLDB	Geo-Location Data Base
IEEE	Institute of Electrical and Electronics Engineers
ITU	International Telecommunication Union
JTFER	Joint Task Force ERM / RRS
LAA	License Assisted Access
LC	LSA Controller
LR	LSA Repository
LSA	Licensed Shared Access
LSRAI	LSA Spectrum Resource Availability Information
LTE	Long Term Evolution
LTN	Low Throughput Network
MFCN	Mobile/Fixed Communications Networks
Ofcom	Office of Communications (UK)
OAM	Operation, Administration and Maintenance
PAR	Project Authorization Request
PHY	Physical layer
QoE	Quality of Experience
RAS	Radio Access and Spectrum – cluster projects
RPI	Radio Programming Interface
RRFI	Reconfigurable Radio Frequency Interface
RRS	Reconfigurable Radio Systems
SDO	Standards Developing Organization
SDR	Software Defined Radio
SRD	Short Range Device
TVBD	Television Band Device
TVWS	TV White Spaces
URAI	Unified Radio Application Interface
WG	Working Group
WG	Working Group
WSD	White Space Devices
WSDB	White Spaces Data Base

1 Introduction

The realisation that spectrum access and use must become more flexible and more dynamic has reached now even the last bastions of command and control apportioning of radio resources. The way spectrum licenses are sold and the rules and conditions under which operators can "buy" the licenses mirror the research outcomes and many of the discussions that have been going on over the last two decades in particular.

In addition, the types of peak data rates and the sheer capacity that 5G systems will need to provide will only be possible if there is, apart from the obvious millimetre waves and ever smaller cells, an urgent need to allow even short term sharing and short term dynamic access to really squeeze the last bit of capacity out of the available spectrum (in particular out of the sub-6GHz bands).

To be able to implement the relevant sharing and dynamic access technologies comprehensive understanding on the challenges, both technical and regulatory, the research foundations and the (regulatory) boundaries need to be understood. Furthermore, researchers need good oversight of the standardisation activities and the potential business models as both are pre-requisites for any truly impacting research. Therefore, this document provides a comprehensive overview of the research directions that are currently being pursued in ongoing FP7 as well as in newly started H2020 projects, the actual directions aim at a more dynamic sharing model for shared access, sharing of satellite communication bands, as well as interfaces for access control and signalling. The 5G ppp projects also tackle a large range of spectrum access techniques

Spectrum policy has gone through significant changes over the last few years and regulators have changed much of the ways how spectrum licenses are awarded and under which conditions the spectrum may be used. This report provides a comprehensive overview on the current views and directions in spectrum policy development and in the outlook on bands that will be auctioned in the foreseeable future.

Finally, and most importantly the report endeavours to outline the actual standardisation priorities for projects and researchers in the cognitive radio systems, spectrum and dynamic access domain, all of them feeding into and supporting the options a 5G system may exploit in the medium term.

2 Update of global standardization efforts on CR technology

This section provides an overall update of CR standardization activities in ETSI and IEEE. Understanding of the structuring aspects of standardization activities is very important for research projects in order to select important research topics and promising business directions.

2.1 Update of ETSI RRS standardization activities on CR

ETSI RRS WG1 (System Aspects and Cognitive functionalities):
The progress on WG1 work items has been according to the following:

- The "*System architecture and high level procedures for operation of Licensed Shared Access (LSA) in the 2300MHz – 2400MHz band*" (**TS 103 235**) has been approved by ETSI RRS in September 2015..
- The "*Enabling the operation of Cognitive Radio System (CRS) dependent for their use of radio spectrum on information obtained from Geo-location Databases (GLDBs); Parameters and procedures for information exchange between different GLDBs*" (**EN 303 144**), has been approved.
- The "*Signalling Protocols and information exchange for Coordinated use of TV White Spaces; Part 1: Interface between Cognitive Radio System (CRS) and Spectrum Coordinator (SC)*", (**EN 303 387)** 'Final Draft' has been approved.
- The "*Reconfigurable Radio Systems (RRS); System Architecture and High Level Procedures for Coordinated and Uncoordinated Use of TV White Spaces*" (**REN/RRS-0144 / EN 303 145**), 'Final Draft' has been approved.
- The "*Reconfigurable Radio Systems (RRS); System architecture for information exchange between different Geo-location Databases (GLDBs) enabling the operation of White Space Devices (WSDs)*" (**REN/RRS-0145 / EN 303 143**) 'Final Draft' has been approved.

Next Steps

- TS 102 968 "*System requirements for Reconfigurable Radio Systems operating in IMT-Bands and GSM-Bands for intra-operator scenarios*" is open for further contributions.
- A new work item (LSA stage 3) DTS/RRS-0146 "Reconfigurable Radio Systems (RRS); Information elements and protocols for the interface between LSA Controller (LC) and LSA Repository (LR) for operation of Licensed Shared Access (LSA) in the 2300 MHz-2400 MHz band" has been approved and is open for contributions.

ETSI RRS WG2 (Reconfigurable Radio Equipment Architecture):
The progress on WG2 work items has been according to the following:

- The work on the following work items have been finalized
  - "*Handset SDR Reference Architecture*" (report has been published);
  - "*RBS SDR status, implementations and costs aspects, including future possibilities*" (report has been published);
  - "*Reconfigurable Radio Systems; Multiradio Interface for SDR Mobile Device Architecture and Services*";
  - "*Use cases for baseband interfaces for unified radio applications of mobile device*";
  - "*Reconfigurable Radio Systems (RRS); Requirements for Reconfigurable Mobile Devices*";
  - "*Radio Reconfiguration related Architecture for Mobile Devices*".
- The EN Approval Procedure has been finalized for "*Radio Reconfiguration related Requirements for Mobile Devices*" (**EN 302 969**)
- The EN Approval Procedure is still ongoing for "*Radio Reconfiguration related Architecture for Mobile Devices*" (**EN 303 095**)
- The work has been also finalized for the technical specification on "*Mobile Device Information Models and Protocols; Part 2:Reconfigurable Radio Frequency Interface (RRFI)*" (**TS 103 146-2**)

Next Steps

- To develop an European Standard (EN) on Reconfigurable Radio Frequency Interface (RRFI).
- To achieve technical specifications on Unified Radio Application Interface (URAI) and Radio Programming Interface (RPI)

ETSI RRS WG3 (RRS Security, Certification and Declaration of Conformity):
The progress on WG3 work items has been according to the following:

- The work on "*Security related use cases and inherent Security threats in Reconfigurable Radio Systems*" **(DTR/RRS-03010 (TR 103 087))** is still ongoing and a Specialist Task Force (STF) has been submitted.
- An updated version of the Declaration of Conformity mechanisms for Software Reconfigurable Equipment has been achieved for "*Dynamic Declaration of Conformity*" **(DTR/RRS-03009 (TR 102 967))**.
- A new version of "*Requirements for Dynamic Re-certification*" (DTS/RRS-03011 (TS 103 094)) has been made available as a 'Second Draft'.

Next Steps
- Finalization of "Requirements for Dynamic Re-certification" (**TS 103 094**)
- Revision of "Dynamic Declaration of Conformity" (**TR 102 967**)

ETSI RRS WG4 (Civil Security and Inter-Domain Synergies):

ETSI TC RRS has been working on the "Feasibility study on inter-domains synergies; Synergies between civil security, military and commercial domains" (**TR 103 217**) and made some efforts to involve major stakeholders (commercial, public safety and military). Up to last year, there seems to be no interest from the military stakeholders, very limited interest from the commercial stakeholders and limited interest from the public safety stakeholders. Apparently, it can be considered the topic to be premature whilst waiting for the spectrum allocation decisions to be taken in the upcoming ITU World Radiocommunication Conference 2015 (WRC15) - to be held on November 2015. As such, ETSI has informed the EC that a feasibility study reflecting mature views of the stakeholders on the topic could be delivered not before Q1 2016.

2.2 Update of IEEE standardization activities on CR

The IEEE Standards Association pursues a number of activities that are of particular interest to the RAS cluster activities and dynamic spectrum access research in general. The majority of these activities are clustered under the IEEE 802.11, 802.19 and 802.22 standardisation groups, others under the DySPAN working group which works towards the IEEE 1900 family of standards. The most important and relevant activities and their current status are described below.

IEEE 802.19.1

802.19.1-2014 - IEEE Standard for Information technology--Telecommunications and information exchange between systems -- Local and metropolitan area networks -- Specific requirements -- Part 19: TV White Space Coexistence Methods.
The IEEE 802.19.1 working group considers radio technology independent methods to facilitate coexistence among dissimilar television band devices (TVBDs) and dissimilar or independently operated networks of TVBDs, they are specified in this standard.
The group is active and working at current on the follow up standard: P802.19.1a Standard for Information Technology - Telecommunications and Information Exchange Between Systems - Local and Metropolitan Area Networks - Specific Requirements - Part 19: TV White Space Coexistence Methods Amendment: Coexistence Methods for Geo-Location Capable Devices Operating Under General Authorization (AM), The completion of this and intention to submit for sponsor ballot is expected to take place in late 2015/early 2016.

IEEE 802.11af

The objective of 802.11af was to define modifications to both the 802.11 physical layers (PHY) and the 802.11 Medium Access Control Layer (MAC), to meet the legal requirements for channel access and coexistence in the TV White Space. IEEE 802.11af, is often referred to as White-Fi and Super Wi-Fi,[as it allows wireless local area network (WLAN) operation in TV white space spectrum in the 54 and 790 MHz bands. The approach relies on Cognitive Radio Technology to transmit on unused TV channels, with the standard taking measures to limit interference for primary users, such as analog TV, digital TV, and wireless microphones.

The standard was published in February 2014 and there are no continuation activities at this time; the task force (802.11 TGAF) is remains inactive at this time.

IEEE 802.22a,b

The IEEE 802.22 family of standards for wireless regional area network (WRAN) aims at using white spaces in the television (TV) frequency spectrum. The development of the IEEE 802.22 WRAN standard foresees using cognitive radio (CR) techniques to facilitate sharing of geographically unused spectrum allocated to the television broadcast service, without causing interference, to bring broadband access to remote and sparsely populated areas.

The 802.22. group works also on an amendment to the IEEE Standard for Information Technology--Telecommunications and information exchange between systems Wireless Regional Area Networks (WRAN)--Specific requirements Part 22: Cognitive Wireless RAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications: Policies and Procedures for Operation in the TV Bands Amendment: Management and Control Plane Interfaces and Procedures and enhancement to the Management Information Base (MIB) (i.e. 802.22.a) and the work on this amendment has been completed in 2013.

A second amendment: “Enhancement for Broadband Services and Monitoring Applications” has been pursued, and the amendment has gone through sponsor ballot and was approved, but the standard has not yet been published.

IEEE P1900.6b

The P1900.6 standards groups’ summary claims that “*secondary and opportunistic spectrum use will require reliable dependable trusted spectrum sensing capabilities that are fundamental to any advanced radio systems application. Recently proposed advanced radio systems based on sensing technology combine sensing and the protocols and cognitive engines that use the sensing results into proprietary architectures. This model of development reduces innovation and limits the opportunities for integrating new component technologies for better system performance. Many different sensing techniques have been defined so far, there has been no effort to ensure interoperability between sensors and clients provided by different manufacturers. Sensing techniques have been defined without considering their compatibility with other existing solutions.* The P1900.6 working group develops a set of standards that define the information exchange within such systems.

There are two active standards: 1900.6-2011 IEEE Standard for Spectrum Sensing Interfaces and Data Structures for Dynamic Spectrum Access and other Advanced Radio Communication Systems, and 1900.6a-2014 IEEE Standard for Spectrum Sensing Interfaces and Data Structures for Dynamic Spectrum Access and Other Advanced Radio Communication Systems - Amendment 1: Procedures, Protocols, and Data Archive Enhanced Interfaces.

The working group is currently pursuing a corrigendum to the original standard and a new substandard: P1900.6-2011/Cor 1 IEEE Draft Standard for Spectrum Sensing Interfaces and Data Structures for Dynamic Spectrum Access and other Advanced Radio Communication Systems. - Corrigendum 1 (C)
P1900.6b Standard for Spectrum Sensing Interfaces and Data Structures for Dynamic Spectrum Access and other Advanced Radio Communication Systems. Spectrum Database Interfaces Amendment (AM).
The timeplan foresees that the draft for IEEE 1900.6b will be circulated for sponsor ballot in late 2016 and publication is aimed to take place towards mid 2017.

IEEE P1900.7

Dynamic Spectrum Access demands a flexible radio interface. The IEEE P1900.7 group is targeting a new air interface for white space applications. One of the key requirements relies on the fact that white spaces can be present at various frequencies and even scattered across several channels, thus requiring access to fragmented spectrum. So far, the only technological answer to fragmented spectrum was based on carrier aggregation where parallel RF chains address distinct channels. The carrier aggregation architecture is a fast approach towards fragment bonding but it limits the number of addressed channels. In comparison, P1900.7 relies on FBMC to address spectrum fragments at once via a spectrum polling approach. With this approach the P1900.7 air interface can address a large range of spectrum configurations and take advantage of more spectrum opportunities. The reason why FBMC was selected amongst other modulations, such as e.g. OFDM, is due to its very low adjacent channel leakage. This property is inherent to the modulation itself and can be obtained with virtually no analogue filtering. Relaxing the constraints on the analogue filtering leads to spectrally flexible solutions based on SDR or SDR-like implementations.

Despite initial specifications of P1900.7 were focussing on White Spaces, it can be observed that current 5G requirements have similar expectations on interference management (adjacent carrier leakage), and dynamic spectrum access, including access to fragmented spectrum. Besides, FBMC has very good properties to address asynchronous users, which is yet another interest of 5G systems. This means that FBMC standardization effort could be extended to other bodies, such as 3GPP. The IEEE P1900.7 standard is expected to be published in H1 2016. As a consequence, potential extensions of P1900.7 activities may consider its extension to 5G context, where resource allocation and management is very different to what was considered in 1900.7. One example is the ability of FBMC to support asynchronous access. This specific feature can help 5G systems to reduce signalling overhead required in OFDM-based systems. Other extensions may include evolutions of the FBMC PHY to support MIMO.

Currently, IEEE 1900.7 group is considering future directions for the 1900.7 family of standards. In particular two main directions have been discussed. One is related to PHY and MAC update to better support IoT applications. The key requirements to be addressed are power efficiency and support of large number of devices, while having more relaxed requirements on delay and data rate. The second direction is small cell high data rate profile for traffic offloading in 5G heterogeneous networks. The PAR (project authorisation request) is currently in preparation.

3 Update of FP7/H2020 research directions in CR and spectrum sharing

This sections provides an update of the research directions of the ongoing EU funded projects working on CR and spectrum related areas, including the new 5G PPP projects (Phase 1). The standardization priorities are specifications that should be pushed to standards in order to enable real-world deployment of the project solutions.

3.1 A more dynamic sharing model for LSA

The main objective of ADEL project is to explore the potential of LSA as a key enabler of 5G mobile broadband networks by developing:

- Collaborative sensing techniques (achieving sensitivity requirements set by regulatory authorities at a minimum communication overhead between collaborating nodes)
- Dynamic, radio-aware resource allocation (distributed and centralized processes offering desired network features such as scalability, trust-control, efficiency, etc.)
- Cooperative communication (dense LSA, small-cell based hierarchical networks)

ADEL proposes the introduction of the LSA approach to more dynamic sharing scenarios, maintaining the requirement that both the incumbent and the LSA licensees benefit from QoS when using the spectrum. In this sense, ADEL proposes the introduction of (possibly) several collaborative spectrum-sensing networks, a spectrum-sensing reasoning module, and details/improves the operation of the LSA controller. ADEL view of LSA follows a more dynamic spectrum sharing approach that includes sensing features, which are currently beyond the scope of the LSA work in ETSI RRS. A successor of the LSA specifications in ETSI RRS WG1 may be appropriate. However, due to some opposition within ETSI WG1, this may not start before next year.

3.2 Sharing satellite bands

As the Internet traffic grows, broadband satellite systems have to increase their capacity and therefore a better spectrum management is required. Until now, the risk associated to the use of shared satellite bands may have discouraged its full exploitation by satellite systems. Cognitive radio techniques may help to minimize this risk under appropriate operational and regulatory conditions.

The CORASAT project investigates the potential of applying cognitive radio techniques in satellite communications in order to increase the spectrum opportunities for future generations of satellite networks without interfering with the operation of incumbent services. In particular, the CORASAT project investigates the co-existence scenarios of FSS (Fixed Satellite Service - earth stations) with FS (Fixed Service – terrestrial link) or FSS feeder links for BSS (Broadcast Satellite Service). The CORASAT project identifies two Ka-band downlink scenarios (17.3−17.7 and 17.7−19.7 GHz) and one uplink scenario (27.5−29.5 GHz) where the enabling CR techniques (sensing and spectrum databases) as well as the regulatory conditions for a safer use of the Ka shared band were investigated.

Simulation results carried out by CORASAT has shown that that both satellite and terrestrial systems could potentially operate in the same Ka band without degrading each other’s performance if appropriate considerations are taken into account and an appropriate design of the interfering system is carried out. Considering a spectrum geo-location database approach it has been demonstrated that an additional 400 MHz is available to the FSS service in more than 95% of EU coverage.

In July 2014, ETSI TC-ERM approved and published the TR Document entitled "Cognitive radio techniques for Satellite Communications operating in Ka band" which reflect several outcomes of the CoRaSat study.

3.3 The need of unified control interfaces

Wireless networks have recently evolved to very complex systems, due to the increasing diversity of competing radio technologies, applications and service providers which coexist in the same environments. In such a scenario, the performance optimization mainly depends on the availability of suitable software platforms for controlling and coordinating radio communication and network protocols within the complex wireless ecosystems. The WiSHFUL project addresses these issues by proposing a flexible and unified radio and network control framework for standardized technologies as well as Software Defined Radios.

The WiSHFUL project proposes a unified radio and network control interfaces for off-the-shelf as well as advanced SDR equipment that allow customizing wireless access solutions for specific networking and traffic contexts. The proposed unified radio control abstracts hardware specific instructions and thus enables full, vendor independent radio control, while the unified network control allows rapid prototyping and adaptations of network protocol stacks in a heterogeneous, multi-vendor environment. These abstractions allow experimenting with flexible control of radio communication and network stacks, in turn enabling intelligent, node-level and network-wide decisions on radio and network operation modes and settings, driven by higher-level domain specific application demands and taking into account external policies (e.g, policies for dynamic spectrum access). At standardization level WiSHFUL is following and contributing to the SDR architecture specifications developed in ETSI RRS WG2.

3.4 Research directions of CR and spectrum in 5G PPP

The 5G Public-Private Partnership (5G PPP) is an instrument launched as part of Horizon 2020, with a budget of €700 million in public funding expected to leverage five times this amount (€3.5 billion) in private investment.

In particular the view on use and access of spectrum documented in the Vision document developed for MWC 2015[1] is relevant in this context. It is expected that 5G access networks, at least for some services will require very wide contiguous carrier bandwidths (e.g. hundreds of MHz up to several GHz) to be able to provide a very high overall system capacity. To support the requirements for wide contiguous bandwidths, higher carrier frequencies above 6 GHz need to be considered. The consideration of any new bands for such services will require careful assessment and recognition of other services using, or planning to use, these bands. Maintaining a stable and predictable regulatory and spectrum management environment is critical for the long term investments. Research on this spectrum has to take into account long-term investments so that they can be preserved. The exclusive mobile licensed spectrum assignment methods will remain important even if new techniques may be envisaged to improve spectrum utilization under some circumstances.

While all 5G-PPP projects are working on particular aspects of a future 5G system, there are a subset which, in particular tackle spectrum access and spectrum sharing related issues in more detail. The majority of these projects has been kicked off in Q3 2015 and are in their early stages of system and access architecture definition and only little information about the actual access architecture has yet been agreed (note, the 5G PPP working group on the 5G architecture is planning to release a white paper outlining the first version of the architecture in the course of Q1 2016).

The 5G-PPP projects that are relevant to the main topics of the RAS cluster and their main interest in spectrum access and dynamic spectrum exploitation include:

5G-PPP project	**Spectrum related activity**
SPEED-5G	New waveforms and MAC for 5G, ultra-dense deployments of small cells
FANTASTIC 5G	Flexible air interface in 5G
COHERENT	Spectrum management in 5G
METIS-II	Novel spectrum sharing techniques and novel air interfaces in higher frequency bands

[1] https://5g-ppp.eu/wp-content/uploads/2015/02/5G-Vision-Exec-Summary-v1.pdf

4 Evolution of the EU spectrum policy

4.1 The radio spectrum inventory and subsequent steps

The European Radio Spectrum Policy Programme (RSPP), adopted in March 2012 by the European Parliament and the Council of the European Union, foresaw in the establishment of an inventory of spectrum for both commercial and public use in the frequency range between 400 MHz and 6 GHz. The objective of this measure was to identify bands in which more efficient use of spectrum could be organized, bands that could be suitable for reallocation or shared use of spectrum, the various types of spectrum use by public and private entities, and to assess potential impact of such reallocation to these as well as to adjacent bands.

In April 2013 the Commission adopted an Implementing Decision defining practical arrangements, uniform formats, and a methodology in relation to the spectrum inventory. As part of the procedure, the Commission reported on the progress in establishing the Spectrum Inventory for the first time in September 2015. **Error! Reference source not found.** The report gathers data from a number of deliverables and reports, from data delivered by the Member States to the Frequency Information System (EFIS database) of ECO and from information delivered directly by the Member States. However, the Commission reported that *"difficulties have been encountered in collecting the data due to diverse data formats, multiple transfer means, confidentiality claims and questions about privacy protection."* As a result, the Commission currently considers its own data analysis tool as insufficient to draw comprehensive conclusions on spectrum use in the 400 MHz-5GHz band and had to rely on addditonal source.

Nevertheless, the inventory has already yielded interesting results. There seem to be little services using radio frequencies that will need significantly less spectrum in the future, rendering reassignment of frequencies complex and costly. The Commission therefore concludes that *"a sustainable way to satisfy spectrum demand in the medium and long term is to invest more time and resources in identifying and developing more sophisticated spectrum sharing concepts as detailed below, subject to the protection of effective competition.*

- *Licensed Shared Access (LSA) assignment;*
- *Geographical spectrum sharing with devices linked to geo-location databases (once available); and*
- *Making more effective use of existing networks and spectrum assignments through densification, increase in spectrum re-use, and spectrum sharing between operators."*

As already mentioned in D2.4 (section 2), the European Commission has taken significant steps towards the introduction of LSA (with the support of CEPT, ETSI and the RSPG) and towards geo-location based spectrum sharing, while also investigating the possibility of sharing in the radar bands between 2700 and 2900 MHz, possibly for PMSE, and in the 870-876 MHz and 915-921 MHz bands (primarily used by GSM-R and the military) for short range devices. Related to this, the report also comes to the conclusion that there is currently no need for additional spectrum harmonization for licensed wireless broadband, beyond the 1200 MHz target, in the 400 MHz-6 GHz range. The reasons for this are significant under-utilitization of mobile broadband bands in many Member States due to lack of demand and/or usage difficulties, the probable need of very large channels above 6 GHz for future 5G systems, and the high remaining potential of more sophisticated spectrum re-use (small cells, mobile offloading, technologies that better exploit the available spectrum) for capacity increase.

Specifically with regard to the need of broadband spectrum (a topic for example important with regard to the use of TV white spaces), the Commission notes that pressure on the UHF band is expected to grow, since all users in this band have increasing spectrum needs. In this context, the Commission has taken several initiatives ahead of the 2015 World Radiocommunications Conference:

- Mandate to CEPT to develop technical conditions for wireless broadband in the 694-790 MHz (700 MHz) band **Error! Reference source not found.**. The resulting deliverable, CEPT Report 53 was approved on 28 November 2014 by the ECC. The report outlines a preferred technical arrangement as well as common and minimal (least restrictive) technical conditions for wireless broadband use in the 694-790 MHz frequency band for the provision of electronic communications services. In doing so, CEPT also accommodates for both PPDR services and for incumbent users such as PMSE. The band plan decided upon consists of 2x30MHz FDD combined with an optional Supplemental Downlink (SDL) in the duplex gap, with various alternative options for the accommodation of PMSE, PPDR and M2M. The report also defines the common and minimal (least restrictive) technical conditions for the use of this band.

- Request for Opinion to the RSPG on developing a long-term strategy for the UHF band. The Opinion was published in February 2015 **Error! Reference source not found.**. It fully supports the introduction of Wireless Broadband in the 700 MHz band, and asks Member States to take measures in order to reallocate the band as soon as possible (i.e. available for effective years by 2020), move remaining broadcasting channels to lower bands and coordinate between each other and with non-EU border nations (before end of 2017). For what concerns the band 470-694 MHz band, the RSPG recognizes the importance of digital broadcasting and asks that the band remain available for DTT in the foreseeable future (i.e. 2030). However, the Group also recommends that Member States should have the flexibility to use the 470-694 MHz band for WBB downlink, provided that such use is compatible with the broadcasting needs in the relevant Member State and does not create a constraint on the operations of DTT in neighboring countries. It asks that, when making this decision, requirements, technological developments, consumer behavior, the importance of delivering free-to-air television and the various political, social, cultural and economic general interest objectives, be taken into account. Finally, the Opinion also provides recommendations on PPDR (deemed important) and PMSE (which needs protection and possibly more spectrum, but also better technology)

- High Level Group of industry representatives to provide strategic advice to the Commission on future use of the UHF band. A report on the activities and conclusions of this Group was presented to the Commission by its chairman, Pascal Lamy, in September 2014 **Error! Reference source not found.**. Similar to the RSPG, the report recommends the release of the 700 MHz band for broadband in 2020 and the safeguarding of the bands below 700 MHz for broadcasting until 2030, while a stocktaking of market developments needs to take place by 2025. The report also advocates the study of flexible use of the lower bands for both broadcasting and downlink-only broadband, subject to national requirements and recognizing broadcasting as primary use.

- Study on the challenges and opportunities for convergence of terrestrial wireless platforms. This study, performed by Plum and Farncombe, was finalised in December 2014. **Error! Reference source not found.** Its main focus was on assessing the costs and benefits of a converged platform for broadcasting and wireless broadband; the most suitable solution for this would be to transfer DTT from its current High Power/High Power topology to the Low Tower/Low Power architecture present in mobile broadband networks. Due to market uncertainties expected to disappear within the next 3 to 5 years, the study was not able to make a convincing case for such a converged platform. It recommended further study, and close involvement of the broadcasting industry in the development of 5G standards.

4.2 Digital Single Market

For the new European Commission, the creation of a Digital Single Market (DSM) is one of the top priorities **Error! Reference source not found.**. The Commission defines a DSM as *"one in which the free movement of goods, persons, services and capital is ensured and where citizens, individuals and businesses can seamlessly access and exercise online activities under conditions of fair competition, and a high level of consumer and personal data protection, irrespective of their nationality or place of residence."*. In May 2015, the Commission outlined its strategy for achieving this goal. It is based on three pillars:

- *"Better access for consumers and businesses to digital goods and services across Europe (making sure the Internal Market is ready for the digital age with rapid actions, and helping to ensure a "single" digital market by removing barriers that hold back cross-border e-commerce);*
- *Creating the right conditions, level playing field and environment for digital networks and content services to flourish (actions to create the right conditions for infrastructure investment, ensuring a level playing field between market players and improving the European basis for the digital economy);*
- *Maximising the growth potential of the digital economy (actions with far-reaching effects on European industrial competiveness, investment in ICT infrastructures and technologies such as Cloud computing and Big Data, research and innovation as well as inclusiveness and skills). "*

Under the third of these pillars, the Commission plans to take steps to harmonize spectrum regulations in Europe, since the *“absence of consistent EU wide objectives and criteria for spectrum assignment at national level creates barriers to entry, hinders competition and reduces predictability for investors across Europe.”* This implies, in first instance, a common and harmonized approach to the reallocation of the 700 MHz band.

4.3 The new Radio Equipment Directive (RED)

In May 2014, the European Commission published a new Directive for Radio Equipment **Error! Reference source not found.**, repealing the famous R&TTE Directive (1999/5/EC) on radio equipment and telecommunications terminal equipment, which specifies conformity rules and procedures for his type of equipment allowing the use of the CE mark. The Directive is the main route towards compliance for all radio equipment sold in Europe.

The new version of the Directive (which no longer applies to Terminal Equipment) finally contains much needed provisions on conformity of Software Defined and Cognitive Radios. First, Article 3 states that *“Radio equipment within certain categories or classes shall be so constructed that it... supports certain features in order to ensure that software can only be loaded into the radio equipment where the compliance of the combination of the radio equipment and software has been demonstrated.”* (Art 3(3)(i)).

Furthermore, Article 4 of the Directive (“Provision of information on the compliance of combinations of radio equipment and software“) is dedicated to SDR entirely:

> *1. Manufacturers of radio equipment and of software allowing radio equipment to be used as intended shall provide the Member States and the Commission with information on the compliance of intended combinations of radio equipment and software with the essential requirements set out in Article 3. Such information shall result from a conformity assessment carried out in accordance with Article 17, and shall be given in the form of a statement of compliance which includes the elements set out in Annex VI. Depending on the specific combinations of radio equipment and software, the information shall precisely identify the radio equipment and the software which have been assessed, and it shall be continuously updated.*
>
> *2. The Commission shall be empowered to adopt delegated acts in accordance with Article 44 specifying which categories or classes of radio equipment are concerned by the requirement set out in paragraph 1 of this Article.*
>
> *3. The Commission shall adopt implementing acts laying down the operational rules for making the information on compliance available for the categories and classes specified by the delegated acts adopted pursuant to paragraph 2 of this Article. Those implementing acts shall be adopted in accordance with the examination procedure referred to in Article 45(3).*

As mentioned in §3 of this article, the Commission will now need to specify further regulations with regard to the information on the compliance of hardware/software combinations. The Directive is scheduled to be implemented in national law of the member states by 12 June 2016.

4.4 Spectrum for 5G

With projects such as METIS, 5GNOW and the new projects of the wider and highly ambitious 5G Public Private Partnership, the European Commission is underlining the objective of playing a leading role in the global development of next generation wireless broadband. Meanwhile, in its Strategic Plan 2015-2020 the CEPT stressed the identification and harmonization of frequencies for 5G as one of its top priorities. **Error! Reference source not found.** This includes “traditional” bands below 6 GHz, but also previously unused bands in higher frequencies. However, as the CEPT notes, *“even if CEPT had developed proposals for additional bands for WRC-15, we have certainly reached a point where any additional bands would be under significant sharing constraints. There is a need to provide and secure spectrum access in the same range to other services and applications, i.e. radio-navigation (GPS/GALILEO/GLONASS), civil aviation, scientific /meteorological use of spectrum, satellite communications, safety, defence, etc.”.* Sharing will therefore be a necessity in many bands. On the positive side, the CEPT expects that the *“intrinsic flexibility and adaptability which will be part of 5G may offer side opportunities in terms of more efficient spectrum management. It will facilitate spectrum sharing with other users of the spectrum (e.g. under the Licensed Shared Access approach) or between access and backhauling networks.”* ***Error! Reference source not found.***

5 Standardization priorities and gaps

Despite the large scale of activities, projects and initiatives, there are still a number of areas that need attention and where solutions have to be found. Current research covers already a great many of these issues and goes, in some aspects beyond what the relevant standardization bodies are covering at this time. This section and its parts discuss the most important topics/themes that need to be tackled in forthcoming standards to pave the way for these ideas and approaches being moved to the market.

5.1 Security for CR/DSA in ETSI RRS

Reconfigurable platforms have been used for a long time (for instance in Mobile Devices or Base Stations) but, until now, the solutions have been proprietary and (radio) reconfigurability has been limited and decided by the manufactures themselves, which has limited the vulnerability of the platforms to cyber-attacks. With the development of standardised solutions for new advanced features such as cognitive radio, it is expected that more and more devices will make use of reconfigurable solutions. Future reconfigurable platforms, such as mobile devices, are expected to be more open: for instance a reconfigurable mobile device might be (radio) reconfigured by a third-party application. Even the new Radio Equipment Directive (RED) introduces new specific requirements related to software reconfiguration of radio equipment and security will be very important for fulfilling those same requirements.

Security is therefore of paramount importance in order to make the reconfigurable platform future-proof. If security is not properly defined, there is a high risk that a reconfigurable platform, wherever applied, will be “weak” and therefore could be subjects to cyber-attacks which could damage not only the end user (denial of service, decrease in QoS, etc) but also the overall management of the radio spectrum.

This means that security threats have to be properly investigated and solutions to overcome those same threats developed. ETSI RRS is currently working on the creation of a technical specification defining the security requirements related to reconfigurable radio systems, after that it will be possible to have a baseline for the improvements of the related reconfigurable architectures which are currently under development in TC RRS.

In order to foster the development of the specifications DTR/RRS-03010 (Security related use cases and inherent Security threats in Reconfigurable Radio Systems) and DTS/RRS-03012 (Security requirements for reconfigurable radios), the specialist task force for Reconfigurable Radio Security (STF 502), has been initiated. The preparatory meeting took place on 7th September in Sophia Antipolis, with the participation of CRS-i member Michael Gundlach (Nokia) as member of the STF’s advisory board.

5.2 Joint optimization of new PHY and MAC

Today, the convergence of technologies lies down typically at the IP plane. Unfortunately, wireless technology management is hidden at this level and cannot be optimized. For the same reason, quality of experience (QoE) cannot be managed at this level either. The need for a better exploitation of heterogeneous wireless resource, along with the need to support QoE requirements constitute fundamental observations on current and future evolutions needed by wireless connectivity.

The QoSMOS project has addressed various protocols and resource scheduling mechanisms, and identified the need of spectrum allocation and spectrum management at 2 different tiers acting at different time scales. Namely, resource allocation at the link level required high level of flexibility and demands a cross layer approach to control PHY and MAC allocation and scheduling at a short timescale and in a flexible way.

The first ingredient to such a highly versatile approach is a flexible PHY. Research into an FBMC has shown much better interference behaviour than Orthogonal Frequency Division Multiplexing (OFDM) based systems For instance, interference in adjacent band of an FBMC transmitter is the same as the one of an OFDM TX which operates with a 9dB lower transmit power. This 9dB margin can be used either to extend coverage (by increasing the FBMC TX power by 9 dB) or to increase the number of users per channel with the same TX power, as the aggregated adjacent interference will be far lower than the one with OFDM. In both cases, capacity is increased and interference is better controlled. Thus, FBMC could make even more spectrum available by reducing required guard bands between users (for a given protection margin) and thereby increasing overall capacity. For similar reasons, flexible spectrum harvesting and aggregation can be carried out by nulling carriers located where harmful interference shall be avoided, making FBMC a very flexible approach to spectrum bonding. More specifically, the almost perfect separation between adjacent spectrum sub-bands offered by the FBMC PHY, combined with its in-built filtering capability, allow the access to multi-band fragmented spectrum without the need for complex and programmable band-pass or analogue transmit filters.

The FBMC PHY layer proposed by CRS-i member CEA-LETI in IEEE P1900.7 has a high degree of flexibility. First a set of 7 MCS (Modulation and Coding Scheme) are available and can be selected by the MAC or upper layers according to channel conditions and QoS requirements. Along with the significant range of MCS, the standard also allows 4 carrier spacing schemes to address different channel length environment. These schemes are mapped in the 2MHz and 8MHz profiles. The 2MHz profile is particularly interesting because it enables a very flexible channel allocation where several fragments are bounded, would they be adjacent or not. This is exploited at the MAC to enable highly flexible allocation schemes to cope with a huge set of spectrum profiles and/or QoS environment.

5.3 Future perspectives for LSA in ETSI and 3GPP

Within ETSI RRS, the stage 3 of LSA has started with the adaption of the new work item DTS/RRS-0146 "Reconfigurable Radio Systems (RRS); Information elements and protocols for the interface between LSA Controller (LC) and LSA Repository (LR) for operation of Licensed Shared Access in the 2300 MHz-2400 MHz band". This Technical Specification defines the content of the LSA Spectrum Resource Availability Information (LSRAI) and the protocols on the interface between LSA Controller (LC) and LSA Repository (LR), the so-called LSA1. The work will be based on the System Requirements defined in ETSI TS 103 154 (System requirements for operation of Mobile Broadband Systems in the 2300 MHz - 2400 MHz band under Licensed Shared Access (LSA)) and the System Architecture and High Level Procedures defined in ETSI TS 103 235 (System Architecture and High Level Procedures for operation of LSA in the 2300 MHz-2400 MHz band). Application to other bands is not precluded and depends on future regulatory decisions. This work shall be finalised until September 2016.

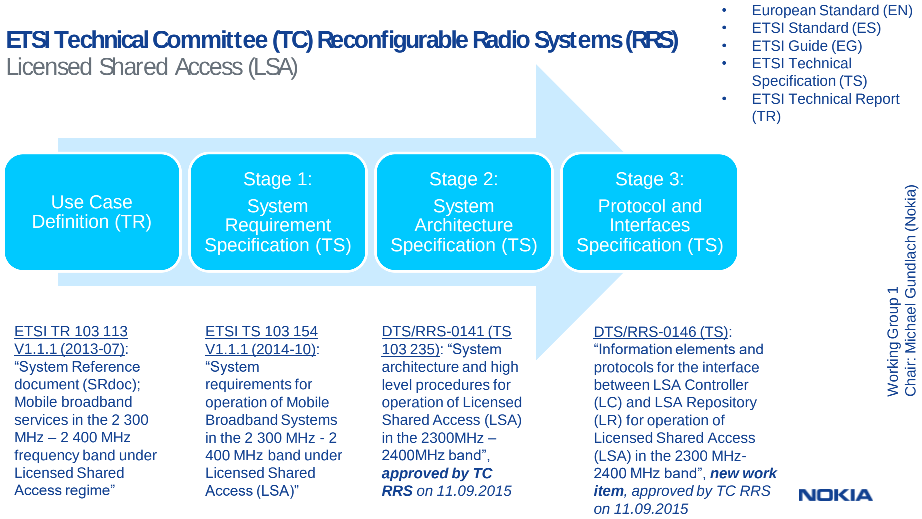

Figure 1 LSA specifications of ETSI RRS.

Within 3GPP SA5, the protocol between the LC and the Operation, Administration and Maintenance (OAM) of the mobile network operator will be specified. A related study item shall be performed until end of this year (2015).

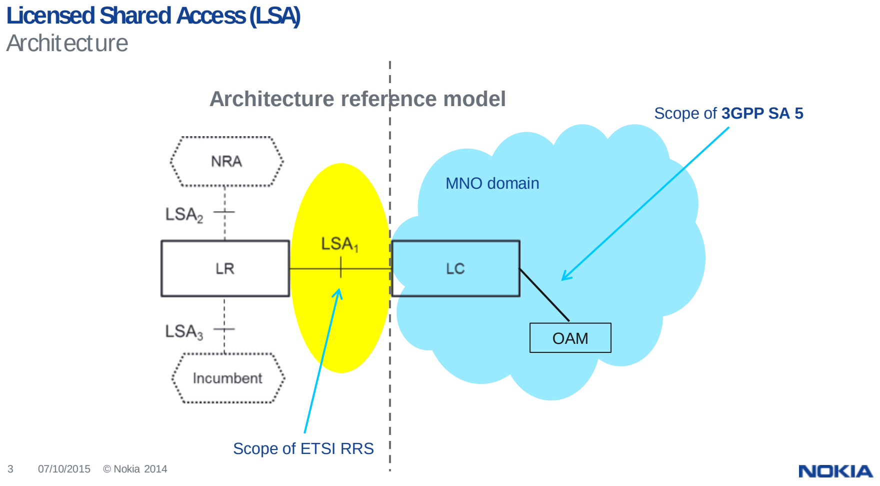

Figure 2 Work distribution between ETSI RRS and 3GPP SA 5

By these two activities, the deployment of a standardized LSA will be possible.

These activities are done according to liaisons between ETSI RRS and 3GPP SA. In addition, both groups liaise with the WInnForum that is specifying SAS, a similar approach as LSA for 3.5GHz.

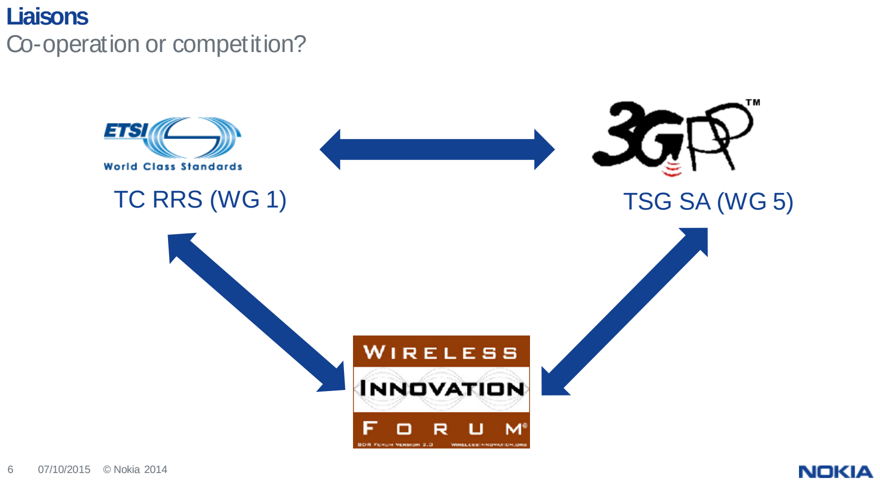

Figure 3 Liaisons regarding LSA and SAS

The specification of an enhanced LSA could not be started yet due to the opposition of some participants. However, a new approach to this will be started next year (2016) and there are plans that input from the ADEL project as well as from other research projects will be used for this.

5.4 Future perspectives for LTE-U (LAA) in 3GPP

LTE networks carry a huge amount of data, driven by a growing number of LTE subscribers that reached almost 300 million by mid 2014. Radio capabilities have also been evolving rapidly with the development of LTE-Advanced, enabling a commercially available peak data rate, with carrier aggregation, of 300 Mbps during 2014. **As part of 3GPP Release 13, a new activity has been started using unlicensed spectrum with LTE alongside licensed spectrum. This is known in 3GPP as License Assisted Access (LAA).** It is sometimes also referred to as LTE-U (LTE-Unlicensed). LAA would allow operators to benefit from the additional capacity available from the unlicensed spectrum, particularly in hotspots and corporate environments. With LAA, the extra spectrum resource, especially on the 5 GHz frequency band, can complement licensed band LTE operation.

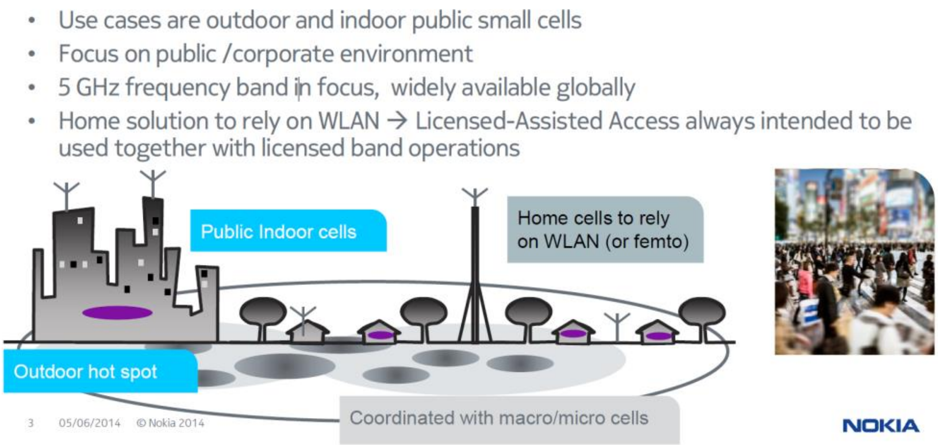

Figure 4 Motivations for Licensed-Assisted Access (LAA)

LAA will allow co-existence with Wi-Fi without any specific coordination and will meet all the regulatory requirements for 5 GHz unlicensed band operation. This is an important feature of LAA which allows deployment in the same markets, such as shopping malls and corporate environment, as Wi-Fi networks. LTE for unlicensed band will rely on the existing LTE core network and will use the existing LTE security and authentication framework, meaning no changes in the core network domain will be required. The use of LTE unlicensed together with the licensed band operation brings a major capacity boost from the unlicensed band while still ensuring end user quality of service, regardless of the interference situation in the unlicensed band.

The specification work for Release 13 LTE operation in unlicensed spectrum is expected to be done by mid-2016. Once the basis is specified, 3GPP will define the necessary bands and band combinations to be used with the 5 GHz band, which can be done as Release independent on top of Release 13.

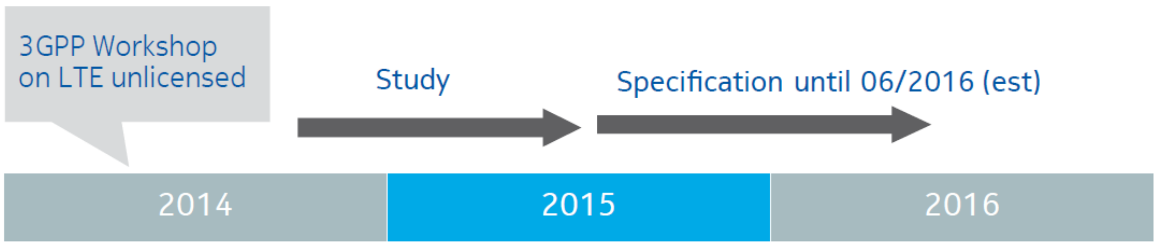

Figure 5 3GPP timeline for the work on LTE for unlicensed band

Within 3GPP, there is a view that **unlicensed spectrum access is regarded as a key part of 5G** with many envisioning a unified approach for licensed, shared and unlicensed spectrum. The 3GPP and IEEE work on coexistence for LAA and Wi-Fi to fairly share unlicensed spectrum appears to be only the first phase of a longer term relationship between these communities. Issues regarding a common unlicensed spectrum access protocol are of interest to support high performance for 5G cellular, Wi-Fi and other technologies using shared unlicensed spectrum.

5.5 Future CR enabled Short Range Devices or Spectrum sharing for IoT

As outlined in [10], there is a view that cognitive radio technology will play a major role in the short range/M2M and IoT areas. Looking at the actual devices, many of the sensors connected will be in form of Short Range Devices (SRDs). The area of SRD standardisation is well covered as ETSI developed four generic standards (EN 300 220; EN 300 330, EN 300 440 and EN 305 550) and a number of specific standards covering specific applications and application areas. SRD applications are not identified as a radio service in Radio Regulations. In other words, SRDs can therefore operate everywhere in the frequency spectrum under the following conditions:

1. SRDs operate in shared bands and are not permitted to cause harmful interference to radio services. This condition is usually enforced by setting clear spectrum masks for these technologies under harmonized standardization.
2. SRDs cannot claim protection from radio services.

These conditions, associated with the fact that SRDs are most usually authorized under a general authorizations regime (i.e. license exempt), are defining the appropriate regulatory framework.

With the new low power long range systems operating at subGHz frequencies, it is becoming less clear whether such low power operating in the licence exempt bands can be classified under SDR. Of course, the band in which they operate, and the fact that they do not belong to a radio service in particular would argue for such a classification. However, the very high link budget they claim (typ. 150 to 160dB) would rather categorize them in very large cell systems. ETSI classifies them into Low Throughput Network (LTN) technology, i.e., a wide area bidirectional wireless network with key differentiators compared to existing networks. LTNs enable long-range data transmission (distances around 40 km in open field) and/or communication with buried underground equipment and operates with minimal power consumption allowing several years of operation even with standard batteries.

The main players in this arena, historically the pioneering company Neul, then Sigfox and Semtech, started to follow a quick market adoption to enforce a *de facto* standard rather that going through the technology standardization process. Neul for instance has launched the Weightless SIG which is independent to usual standard bodies. Sigfox is promoting its own Sigfox ready label in order to build an ecosystem around its technology. Semtech, as a chip vendor, rather try to push their chipsets into equipment. More recently, the ETSI groups dedicated to Low Throughput Networks technology has released the first three specifications of an Internet of Things (IoT) network dedicated to low throughput communications under the initiative of Sigfox, Semtech, Orange and few others.

"*These new requirements provide a breakthrough in the machine to machine business, allowing object connection for a few euros per year, with a few milliwatts for transmission and a modem costing less than 1 euro. The key to the success of IoT standardization and implementation, these assumptions are the basis for many new and innovative applications.",* ETSI reports.

The three new ETSI group specifications defining LTN are GS LTN 001 containing the use cases, GS LTN 002 describing the functional architecture and GS LTN 003 defining the protocols and interfaces.

IEEE also have some dedicated groups related to Machine to Machine communication under the premises of 802.15m and 802.11af operating in the TVWS and the sub-GHz ISM band respectively.

From this overview, it clearly appears that LTN are a new and hot topic and attracts various technical solutions. The GS LTN 003 may seem to indicate that some common technical baseline is established, but actually, going into the details of this standard reveals that it encompasses two profiles, namely the Ultra Narrow Band (UNB) profile (apparently more favourable to Sigfox) and the Orthogonal Sequence Spread Spectrum (OSSS) profile (apparently more favourable to Semtech). This example clearly shows that standardisation consolidation on this kind of technology is not really taking place and will be driven by market decisions.

5.6 Spectrum sharing in military bands

Military bands account for 19% of the available spectrum below 1 GHz in the EU, moreover military spectrum use in the EU is often limited to specific locations or times (e.g. training exercises). However spectrum sharing in military bands with civil applications faces many challenges such as [11]:

- International agreements (e.g. NATO) and obligations concerning global interoperability (e.g. aircraft/ships).
- Coexistence studies are needed for potential sharing bands, but for this detailed specifications of incumbents and CR devices are needed. Disclose of military radios coverage for coexistence studies and computation of exclusion protection areas (e.g. in primary radar bands) is very challenging because of national security concerns.
- Typical military radio upgrade cycle is 15 years with low market volumes and high unit costs which leads to a lack of incentive to upgrade radio equipment that enables a more efficient use of spectrum.

In this context, the EC Mandate (M/512) to ETSI on Reconfigurable Radio Systems includes in its Objective B the Civil Security and Military domain. However, on request from the EDA (European Defence Agency), this objective is currently “frozen” until at least the end of 2015. A Defence Standardisation Coordination Group (DSCG) was created in July 2014. The DSCG will not develop standards itself but aims to be the single interface in Europe between defence standardization needs (the procurers of defence materiel – the military) and defence standards developers (the industry).
DSCG is a forum where stakeholders can discuss technical defence/hybrid standardisation projects which can be managed by open Standards Developing Organizations (SDOs). Once a standardization proposal is brought to the attention of the group and no overlapping with existing activities exists, the proposal, upon agreement, is handed over to the most suitable European Standardization Organization (CEN, CENELEC or ETSI) or, if this is not possible (for instance whenever an open SDO is not considered to be suitable), to other relevant bodies (such as NATO). The preferred way would be the production of European Standards as this would facilitate defence procurement in Europe and would improve the competitiveness of Europe’s industry.

6 Conclusion

The research into dynamic spectrum use and more efficient exploitation of spectrum covers a large range of topics and different approaches. Some of these approaches have started to receive support from regulators through changes in the way spectrum licenses are defined, and also through the fact that increasingly there are standards defining the boundaries and operational conditions under which spectrum sharing and dynamic access can be implemented while ensuring fairness to all actors.

The current research efforts are rather comprehensive and cover a range of different approaches towards flexible and dynamic radio resource and spectrum usage, many of these approaches are now also mirrored in the ongoing standardisation work in the relevant bodies (ETSI, IEEE, 3GPP in particular) and are likely to become mainstream in future releases of, for example 3GPP standards. However, with the move towards standardisation of a future 5G system a number of new areas in which more research and standardisation efforts are needed are emerging.

Much of the research efforts are currently geared towards delivery of high capacity and high bandwidth services; on the other end of the 5G top level system requirements works towards low energy, low latency systems to support M2M and IoT traffic are also progressing. One large challenge will be to integrate both in standards for a coherent system and at the same time extending the use of dynamic spectrum and spectrum sharing approaches into hitherto protected or unavailable (e.g. military) frequency bands.

The current portfolio of EU funded projects is quite comprehensive yet to be able to fully exploit the potential of cognitive radio technologies for dynamic spectrum access, a range of fields need to be further investigated and appropriate standards need to be developed. These areas include security extensions for CR and opportunistic access systems, as well as optimised interworking between the new PHY and MAC layers that can be expected for a 5G system.
Furthermore, LSA and LAA (i.e. LTE-U) use are not fully explored and the standardisation is still in rather early stages. Similar to this the use of CR for short range devices, which often was seen as being too complex and too costly for low power/low performance devices; in this area there is still significant research and standardisation potential.
Finally, the use of military bands appears to become a potentially viable option, especially with a changing view about their use, there appears to be some relaxation about spectrum sharing in some of those bands however the standards are yet to be developed.

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