CRS-i

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Coordination Action

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

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Position paper on FP7 research directions in CR and the European standardization priorities – initial version

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Abstract:
This position paper describes in a consolidated manner the European research and standardization activities related with Cognitive Radio, Dynamic Spectrum Access and Coexistence issues. The FP7 research activities and standardization priorities are summarized, enabling the identification of standardization opportunities, project synergies and research gaps. This is a fundamental step that the CRS-i consultancy service took towards reaching its main goal, i.e., to strengthen the position of FP7 projects in standardization bodies related to cognitive radio, and to facilitate the pull through of European project outcomes.

Keyword list: Cognitive Radio, Standardization, White Spaces, Licensed Shared Access, Dynamic Spectrum Access, Device-to-Device communications

Executive Summary

This position paper describes in a consolidated manner the European research and standardization activities related with Cognitive Radio, Dynamic Spectrum Access and Coexistence issues. The FP7 research activities and standardization priorities are summarized, enabling the identification of standardization opportunities, project synergies and research gaps. This is a fundamental step that the CRS-i consultancy service took towards reaching its main goal, i.e., to strengthen the position of FP7 projects in standardization bodies related to cognitive radio, and to facilitate the pull through of European project outcomes.

To this end, this deliverable provides:

- A discussion on the evolution of the EU spectrum policy. More specifically, the Radio Spectrum Policy Programme (RSPP) and European Conference of Postal and Telecommunications Administrations (CEPT) responses to the identified need for efficient solutions in order to accommodate the growing demand for data traffic are described. The solutions discussed include the identification of additional spectrum bands that can be allocated for mobile communications, as well as the efficient support of spectrum sharing through Licensed Shared Access (LSA).
- A description of the European Telecommunications Standards Institute (ETSI) response to the European Standardization Mandate for Reconfigurable Radio Systems. A summary of the respective Mandate and its three main objectives is provided, while the ETSI Technical Committee on Reconfigurable Radio Systems (TC RRS) work under Objectives A and C is described.
- A consolidate view of the currently scattered knowledge of standardization groups and work items in different aspects of the CR systems.
- An updated description of the recent and planned standardization efforts in ETSI, IEEE and IETF, with the aim to facilitate the FP7 research projects' understanding of the diverse structural aspects of CR standardization in a global level.
- A summary of main research directions in CR and related standardization priorities for the following FP7 projects: CRS-i, ABSOLUTE, MOTO, EMPhAtiC, 5GNOW, SOLDER, METIS and ADEL. The project standardization priorities are specifications that should be pushed to standards in order to enable real-world deployment of their proposed solutions.
- An analysis of synergies between FP7 projects that concludes with the following opportunities for cooperation in the standards development process:

    - A new Study Item in 3GPP (Rel.13) on Non Orthogonal Waveforms: EMPhAtic and 5GNOW;
    - Joint contributions to 3GPP LTE RAN on D2D (ProSe) to ensure the compatibility of the proposed solutions with the ProSe specifications: ABSOLUTE and MOTO;
    - Joint contributions to LSA system architecture work in ETSI RRS WG1: CRS-i, METIS and ADEL;
    - Joint contributions to White Spaces technologies in DySPAN-SC: CRS-i, 5GNOW and SOLDER;
    - Joint contributions to ETSI RRS WG4: Use Cases, Requirements, Architectures and Interfaces for exploiting synergies among commercial, civil security and military domains and more specifically (Objective C of the EC Mandate M512): ABSOLUTE and EMPhAtic.

- An analysis of recent trends in the area of CR and spectrum coexistence issues that may impact on the future standards evolution.

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List of Abbreviations

BS	Base Station
BER	Bit Error Rate
CA	Carrier Aggregation
CEPT	European Conference of Postal and Telecommunications Administrations
COMP	cooperative multipoint
CP-OFDM	Cyclic Prefix – Orthogonal Frequency Division Mutliplex
CR	Cognitive Radio
CSI	Channel State Information
D2D	Device-to-Device
DMR	Digital Mobile Radio
DSA	Dynamic Spectrum Allocation
EC	European Commission
ECC	Electronic Communications Committee
EDA	European Defence Agency
ERM	ElectroMagnetic Compatibility and Radio Spectrum Matters
EU	European Union
ETSI	European Telecommunications Standards Institute
FBMC	Filter Bank Multi Carrier
FB-SC	Filter Bank Single Carrier
FP7	7^{th} Framework Programme
FS	Fixed Services
GFDM	Generalized Frequency Division Multiplexing
GLDB	geo-location databases
GSO	Geostationary Satellite Orbit
HetNet	Heterogeneous Network
IEEE	Institute of Electrical and Electronics Engineers
IETF	Internet Engineering Task Force
ITU	International Telecommunication Union
JTFER	Joint Task Force ERM RRS
JTRS	Joint Tactical Radio System
LSA	Licensed Shared Access
LTE	Long Term Evolution
MAC	Medium Access Control
MFCN	Mobile/Fixed Communication Networks
MTC	Machine Type Communication
NGSO	Non-Geostationary Satellite Orbit
PAWS	Protocol for Access to White Space Database
PHY	Physical layer
PMR	Professional Mobile Radio
PMSE	Programme Making and Special Events
PPDR	Public Protection and Disaster Relief
PSD	Power Spectral Density
R&TTE Directive	Directive on Radio Equipment & Telecommunications Terminal Equipment
RAT	Radio Access Technology
RF	Radio Frequency
RRS	Reconfigurable Radio Systems

RSPG	Radio Spectrum Policy Group
RSPP	Radio Spectrum Policy Programme
SatCom	Satellite Communication
SCA	Software Communications Architecture
SDR	Software Defined Radio
SRdoc	System Reference document
TC	Technical Committe
TETRA	Terrestrial Trunked Radio
ToR	Terms of Reference
WG	Working Group
WI	Work Item
WLAN	Wireless Local Area Network
WRC	World Radio Conference
WSD	White Space Devices
OL	Overlay
UL	Underlay

1 Introduction

An important objective of the Coordination Action CRS-i is to strengthen the position of European collaborative research projects in standardization bodies related to Cognitive Radio (CR), Dynamic Spectrum Access (DSA) and Coexistence issues. To achieve this, this activity has developed close relationships with a number of related FP7 projects (the CRS cluster projects), in order to identify and support potential standardization strategies for the individual projects as well as potential synergies (such as common topics and strategic interests, coherent use cases, etc.) across projects.

This position paper aims to identify in a consolidated manner the research directions and standardization priorities of FP7 projects. More specifically, this deliverable is structured as follows:

Chapter 2 provides a discussion on the evolution of the EU spectrum policy. More specifically, the RSPP and CEPT responses to the identified need for efficient solutions in order to accommodate the growing demand for data traffic are described , focusing on the need for the identification of additional frequency bands that could be considered for mobile communications as well as the support for efficient spectrum sharing, using schemes such as LSA. Moreover, the CEPT activities in the area of LSA are also overviewed. Finally, the European Commission (EC) priorities with regards the forthcoming World Radio Conference 15 (WRC-15) are also discussed.

Chapter 3, motivated by the increased diversity of identified CR scenarios and system models in a global level, provides a consolidated view of the currently scattered knowledge of the targeted standardization groups in different aspects of CR domains. To this end, it provides an updated overview of the recent and planned standardization efforts in ETSI, IEEE and IETF, thus allowing the interested FP7 research projects to gain a better and deeper understanding of the diverse structural aspects of CR standardization in a global level.

Chapter 4 offers a summary of the main research directions in CR and related standardization priorities for the following FP7 projects: CRS-i, ABSOLUTE, MOTO, EMPhAtiC, 5GNOW, SOLDER, METIS and ADEL. The project standardization priorities are specifications that should be pushed to standards in order to enable real-world deployment of the solution proposed by the project.

Chapter 5 provides an analysis of synergies and opportunities for cooperation between the CRS-cluster FP7 projects in the development of standards. The respective standardization opportunities identified will be communicated to the respective projects through the CRS-i consultancy service, in order to allow them to align their activities with the current trends and future plans in the areas of Television White Spaces (TVWS), LSA and Device-to-Device (D2D) communications.

Finally, chapter 6 identifies research trends in the area of cognitive radio, dynamic spectrum access and coexistence issues, and discusses future directions for standardization.

2 Evolution of the EU spectrum policy

Wireless broadband usage is growing rapidly and is being greatly assisted by the availability of a wide range of mobile devices, such as smartphones, tablets, gaming consoles and other connected devices, and new applications. The continuous development and proliferation of use of numerous applications, services and devices is contributing to a global growth of mobile data traffic, both delivered to and generated by the consumer, at unprecedented rates. The consumer increasingly expects the same quality of service over mobile wireless networks as the one delivered by fixed networks and issues related with demand and capacity can be highlighted.

Broadband penetration and mobility are contributing to, among wide use of multiple applications, the massification of video consumption and consequently a change in traffic demand trends. Consumers increasingly download and watch content anywhere (e.g. Video on Demand, catch-up TV, TV everywhere and place-shifting services). As the Draft ECC Report 188 notes, video consumption is raising issues about the level of asymmetry of mobile data traffic, with "*consumers downloading considerably more than they upload data and multimedia content. The downlink-to-uplink ratios seem likely to widen towards 10:1 in high-traffic areas, as the proportion of video traffic in networks grows*." [22]. But, as RSPG highlights, "*the spectrum efficiency of the downlink is about 2 or 3 times higher than the spectrum efficiency in the uplink*" [1]. Therefore, future channeling arrangements for wireless broadband services and the most efficient way to deliver video services needs to be studied further, as it is unlikely that the use of more frequency-efficient technologies will be able to cater for the growing demand of high bit-rate data services [1]. Currently mobile operators are increasingly using WiFi to offload traffic – "*more than half of all smartphone traffic appears to be routed over Wi-Fi networks, and this nomadic traffic is growing 4-6 times faster than mobile traffic*" [2] – but in this case there is no guarantee of Quality of Service. With the migration to LTE and LTE advanced, a more efficient use of existing spectrum resources is also expected, but the foreseen growth in data traffic may still lead to an additional spectrum need for mobile communications [1].

To meet the growing demand for spectrum, administrations are under pressure to introduce new technologies and regulatory mechanisms. The European Radio Spectrum Policy Programme (RSPP), adopted in March 2012 by the European Parliament and the Council of the European Union, states that at least 1200 MHz of spectrum suitable for wireless data traffic (including frequencies already in use) should be identified by 2015 [3]. In order to identify an additional 1200 MHz of spectrum, Article 9 calls for the establishment of an inventory of spectrum for both commercial and public use in the frequency range between 400 MHz and 6 GHz with the following objectives:

a. to allow the identification of frequency bands in which the efficiency of existing spectrum uses could be improved;
b. to help identify frequency bands that could be suitable for reallocation and spectrum-sharing opportunities in order to support Union policies set out in this Decision, while taking into account future needs for spectrum based, inter alia, on consumers' and operators' demand, and of the possibility to meet such needs;
c. to help analyse the various types of use of the spectrum by both private and public users;
d. to help identify frequency bands that could be allocated or reallocated in order to improve their efficient use, promote innovation and enhance competition in the internal market, to explore new ways for sharing spectrum, to the benefit of both private and public users, while taking into account the potential positive and negative impact of allocation or real- location of such bands and of adjacent bands on existing users.

In this context, the promotion of shared use of spectrum resources is also a valuable mechanism to make available additional spectrum for mobile communications. Licensed Shared Access (LSA) has been recently introduced in regulation and standardization as a complementary approach to traditional licensed and license-exempt approaches and as way to create market-based incentives while providing users with the required legal certainty and quality of service. In its communication of September 2012 and in line with the RSPP, the European Commission proposed to develop two additional tools to provide more spectrum access opportunities for innovative technologies and to incentivise more efficient use of existing spectrum resources: (1) A European approach to identify beneficial sharing opportunities in harmonised or non-harmonised bands; (2) Shared spectrum access rights as regulatory tools to authorise licensed sharing possibilities with guaranteed levels of protection against interference [2]. Within this scope, RSPG has published its opinion in June 2013 and has defined LSA as "*a regulatory approach aiming to facilitate the introduction of radio communication systems operated by a limited number of licensees under an individual licensing regime in a frequency band already assigned or expected to be assigned to one or more incumbent users. Under the Licensed Shared Access (LSA) approach, the additional users are authorised to use the spectrum (or part of the spectrum) in* *accordance with sharing rules included in their rights of use of spectrum, thereby allowing all the authorized users, including incumbents, to provide a certain QoS*" [4]. In practice, the LSA concept allows for more efficient use of spectrum by enabling the incumbent user to continue to use its licensed spectrum, while allowing the use of the same spectrum by other users according to a set of conditions negotiated between the two parties.

In parallel, CEPT has initiated work on the general concept of LSA and two project teams were founded to study the LSA concept. The purpose of the first team, FM 53, is to study the regulatory framework for LSA. It has recently published Report 205 defining the scope of LSA, presenting related regulatory framework, current practices for management of spectrum and frequency authorisations as well as introducing the first practical case of LSA for mobile broadband services in the 2300-2400 MHz band [5]. This band is currently harmonised and used within CEPT for aeronautical telemetry and SAB/SAP, for example for wireless cameras, and also used at a national level for various applications. For this first practical case, CEPT advocates that the implementation of LSA would rely on the concept of a sharing framework, under the responsibility of the National Regulatory Authority. This sharing framework can be understood as a set of sharing rules or sharing conditions that will materialise the change in the spectrum rights of the incumbent(s) and define the spectrum, with corresponding technical and operational conditions, that can be made available for alternative usage under LSA.

The second team, FM52, is studying the applicability of the LSA concept for Mobile Operators in the 2300-2400 MHz band and has recently launched a consultation on the technical and regulatory conditions for the use of this band under LSA for mobile/fixed communication network (MFCN) [6] towards an ECC decision.

Other regimes, such as license-exempt access in the so-called TV White Spaces are also being considered to improve spectrum use efficiency. CEPT has been studying in great detail TV white spaces in the European context and established a dedicated group (SE43) to investigate and define technical requirements for White Spaces operation in the UHF broadcasting band (470-790 MHz). In its Report 159 [7], CEPT focuses on the definition of technical and operational requirements for the operation of cognitive radio systems in this band while protecting incumbent or primary users of the band, such as TV broadcast, programme-making and special events (PMSE), radio astronomy, and aeronautical radio navigation services. The appropriateness of the sensing and geo-location techniques to provide protection to the existing radio services in the context of a diversified range of envisaged deployment scenarios for White Space Devices (WSD) is also studied. However, the spectrum sensing technique is regarded as not reliable enough to guarantee interference protection for DTT receivers and PMSE systems. As follow up, Report 185 [8] expanded the study of the technical and operational requirements for the operation of WSD in the band 470-790 MHz and Report 186 [9] focused on the operation of WSD under geo-location database. It is currently in progress the a new ECC Report (WGFM PT FM53 work item) aiming at describing the overall regulatory framework for the operation of TV WSD using geo-location databases and providing orientation guidelines for national implementation.

In order to meet the goals of the RSPP, the European Commission (EC) is planning to launch a study in 2014 on the challenges and opportunities of broadband-broadcasting convergence in order to achieve better usage of the UHF band in the next year. EC foresees a number of challenges to be addressed.

In preparations for WRC-15, the EC is considering a number of possible EU priorities, including IMT identification in the 1.5 GHz range, allocations to the mobile service in the 5 GHz range, broadband Public Protection and Disaster Relief (PPDR) and a long term strategy for the 700 MHz band [23]. The RSPG is currently developing an opinion on Common Policy Objectives for WRC-15, which will be used as input for further development of EU policy, to guide Member States and to ensure coordination between EU and non-EU countries. Among the issues to be address in this RSPG opinion is spectrum for electronic communications services. The final version of this report is planned for mid-2014.

3 Evolution of CR standardization

An important objective of the coordination action CRS-i is to consolidate the currently scattered knowledge of the standardization groups in different aspects of CR domains and keeping track of new developments in these domains during the project lifetime. This chapter provides a consolidated view of the ongoing activities in ETSI and other standardization organizations.

3.1 The European standardization mandate for RRS

The European Commission (EC) M/512 Standardisation Mandate for Reconfigurable Radio Systems [24] was formally accepted by ETSI in May 2013. Its aim is to identify an approach and a number of issues where standardisation should enable the development and use of RRS technologies in Europe. The main domains of interest of the Mandate are the following:

i. *Commercial domain*
A number of approaches to spectrum policy and to underlying technologies have been proposed in the area of commercial communications in order to exploit the potential of RRS technologies to increase efficiency and flexibility in the use of spectrum. However, there are still substantial uncertainties with regard to decisions relating to spectrum regulation, to the co-existence between incumbent and possible new spectrum users and applications, and to the attractiveness for different stakeholders of associated business models.

ii. *Civil security domain*
The provision of adequate capabilities to civil security organizations is a priority subject for citizens, National Governments and the European Union. The evolution of wireless communications in civil security should address three significant challenges: a) lack of interoperability due to different technology standards and systems, b) lack of broadband connectivity to support a wide range of new applications, c) economic sustainability.

iii. *Military domain*
Today, the Software Communications Architecture (SCA) is the de-facto standard reference for a military SDR architecture.
SCA is a framework on which SDR systems are based, where a framework is defined as a set of cooperating classes that make up a reusable design for a specific class of software.
The issue with the SDR architecture is that “specification development” is being managed as a “procurement activity” supported with government funding. Consequently, specific issues like Security architecture implementation have national or regional interest and can therefore best be handled through government programmes.
The obvious solution is to establish a coordinating committee on European/international SCA based standards where representatives from all relevant national and regional programmes are encouraged to provide broader coordination for the evolution of the SDR architecture worldwide and to facilitate faster and less costly deployment of capabilities into the field.

The three main objectives of the Mandate, addressing both CR and Software Defined Radio (SDR) issues, are depicted in Figure 1 and briefly analysed below.

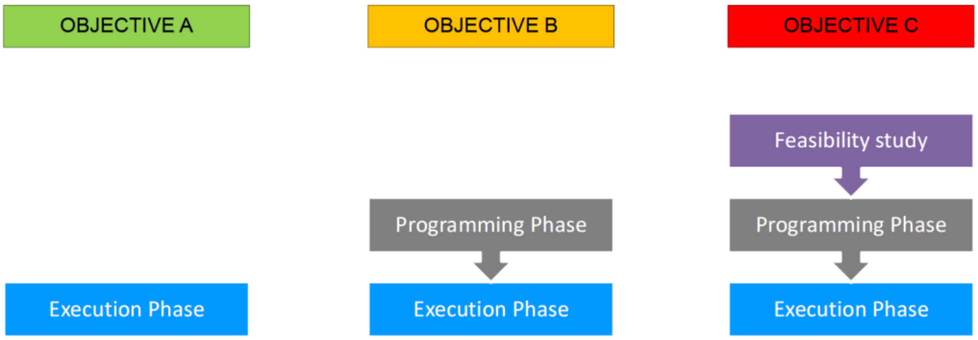

Figure 1: The three objectives of EC Mandate M/512 [source: ETSI].

Objective A
The first objective of M/512 for the Commercial Domain is to enable the deployment and operation of Cognitive Radio Systems (CRSs) including White Space Devices (WSDs) and devices under LSA regime, dependent for their use of radio spectrum upon information obtained from geo-location databases (GLDB).
The main goals of Objective A are the following:

- To allow CRSs and WSDs to comply with EU and national legislation on the placing on the market and the use of radio equipment, in particular with the Directive on Radio Equipment & Telecommunications Terminal Equipment (R&TTE Directive).
- To ensure that implementation of CRS and WSDs technologies does not create barriers to the Single Market.
- To ensure that standardisation of CRS and WSDs technologies happens timely in Europe in order to lead or keep pace with global developments.

The expected output of this objective is the preparation of harmonised standards providing presumption of conformity with Article 3(2) of the R&TTE Directive. The work on this is currently ongoing.

Objective B

The second objective of EC M/512 for the Civil Security and Military Domain is to standardize an SCA-based SDR architecture for the military domain as well as an SDR architecture (for instance "SCA-light") for the civil security domain.

The main goals of Objective B are:

- To facilitate waveform portability and support for intra-border interoperability at national level, cross-border interoperability at the European level, as well as for joint civil security-military operational scenarios.
- To support coordination on SDR architectures with other similar initiatives, such as the Joint Tactical Radio System (JTRS) program in the USA.
- To standardize suitable SDR architecture(s) meeting the specific requirements of civil security and military domains, aiming to facilitate the design of SDR equipment.
- To identify validation and measurements procedures, which can support certification activities.

On request from the European Defence Agency (EDA), this objective isn't currently active.

Objective C

The third objective of the EC Mandate for the Civil Security & Military Domain is to explore potential areas of synergy among commercial, civil security and military applications. These include:

- Architectures and interfaces for dynamic use of spectrum resources among commercial, civil security and/or military domains for disaster relief.
- A reconfigurable mobile device architecture for commercial and civil security applications.
- Other potential synergies to be identified.

The ETSI Technical Committee that is responsible for EC Mandate M/512 is TC RRS. Moreover, ETSI TC RRS and TC ERM have also agreed to create a task force, referred to as Joint Task Force ERM RRS (JTFER) with the aim to develop RRS related Harmonised Standards (and so also the Harmonised Standards developed in response to the mandate). ETSI TC BRAN started the development of the EN 301 598 Harmonised Standard for TV White Space devices before the EC Mandate was actually received and accepted. As that work also fell under the EC Mandate, JTFER assisted TC BRAN in the development and maintenance of EN 301 598. The Harmonised Standard is currently being voted. Any additional Harmonised Standard that may be necessary will be developed under the task force while all other European Standards in response to the mandate will be developed under TC RRS.

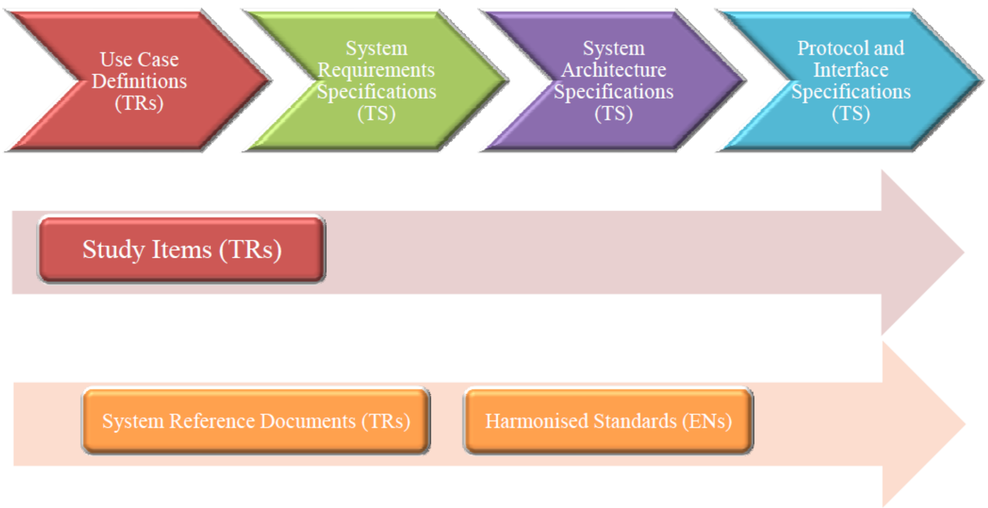

Figure 2: Standardization Process in TC RRS [25]

The TC RRS work under M/512 Objectives A and C is summarized as follows [25]:

Objective A

The Harmonised Standards developed under this objective should at least cover the use case of CRSs operating in TVWS as well as operating under LSA regime.

TC RRS has already published and is currently working on a number of deliverables which are the baseline for all the forthcoming work related to Objective A of the mandate:

Published Specifications on White Spaces

- TR 102 907: Use Cases for Operation in White Space Frequency Bands.
- TR 103 067: Feasibility study on Radio Frequency (RF) performance for Cognitive Radio Systems operating in UHF TV band White Spaces.

Ongoing work

- TS 102 946: System requirements for Operation in UHF TV Band White Spaces, the final draft of which is ready for approval.
- TS 103 145: System Architecture and High Level Procedures for Coordinated and Uncoordinated Use of TV White Spaces, a stable draft of which is available.
- TS 103 143: System architecture for information exchange between different Geo-location Databases (GLDBs) enabling the operation of White Space Devices (WSDs), a stable draft of which is available
- TS 103 235: System Architecture and High Level Procedures for operation of Licensed Shared Access (LSA) in the 2300 MHz-2400 MHz band, an early draft of which is available.
- TS 102 908: Coexistence Architecture for Cognitive Radio Networks on UHF White Space Frequency Bands, an early draft of which is available.
- EN 303 144: 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. An early draft is available.
- EN 303 387: Signalling Protocols and information exchange for Coordinated use of TV White Spaces; Part 1: Interface between Cognitive Radio System (CRS) and Spectrum Coordinator (SC). The work has just started.

Objective C

The ETSI RRS WG4 Terms of Reference (ToR) have been recently refined in order to align with Objective C/Phase 1 of the mandate. Therefore, RRS WG4 will define Use Cases, Requirements, Architectures and Interfaces for exploiting synergies among commercial, civil security and military domains and more specifically:

- Use Cases, Requirements, Architectures and Interfaces for dynamic use of spectrum resources among commercial, civil security and military domains
- Use Cases, Requirements, Architectures and Interfaces related to network sharing between civil security and commercial domain
- Reconfigurable Mobile Device architecture for commercial and civil security applications

ETSI TC RRS has recently adopted a Work Item in response to phase 1 of Objective C, the ETSI TR 103 217 entitled "Feasibility study on inter-domains synergies; Synergies between civil security, military and commercial domains", which intends to explore the potential areas of synergies between commercial, civil security and military domains in the medium/long term (5-15 years) by providing:

- Definitions of use cases
- Definition of potential system requirements
- Discussion of feasibility and implementation obstacles of the use cases, which may include related market information
- Analysis and discussion on the regulatory implications

An early draft of this feasibility study is already available.

As requested by the Mandate, this study is very important as it will provide the baseline for the standardisation work program (Objective C/Phase 2). Therefore commercial, public safety and military stakeholders have to be involved in this work if all potential synergies have to be investigated

3.2 Standardization efforts in IEEE and IETF

An overview of recent CR Efforts in IEEE and IETF is provided by Figure 3. It should be noted that many White Space Medium Access Control (MAC) / Physical layer (PHY) aspects being developed – particularly in IEEE 802: IEEE 802.11, 802.15, 802.16, 802.22. Moreover, IEEE DySPAN-SC [31] is providing supporting technologies including Definitions, Architectures, Language and Sensing.

IETF is addressing White Space Database towards the Protocol for Access to White Space Database (PAWS, currently in its v0.8) [31].

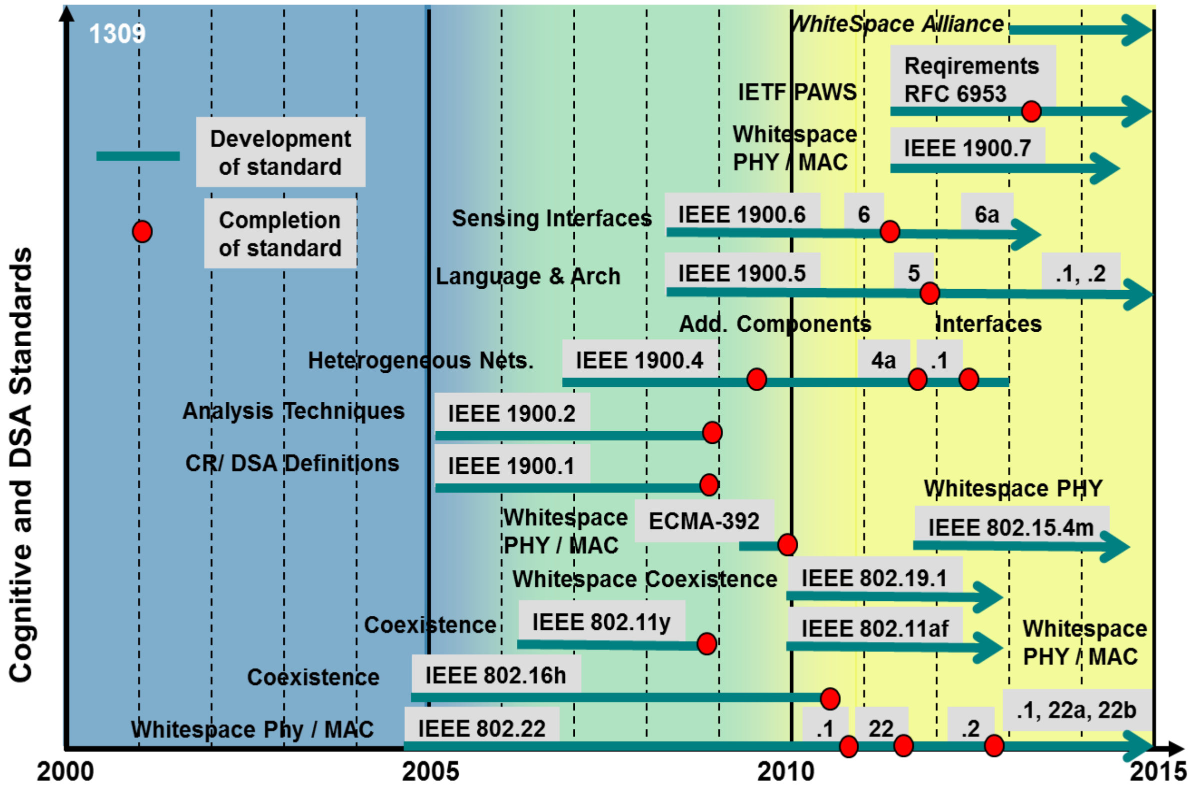

Figure 3: Cognitive Radio efforts in IEEE and IETF [Source: Matthew Sherman].

4 FP7 projects research directions in CR and standardization priorities

This chapter provides a summary of main research directions in CR and related standardization priorities for the following FP7 projects: CRS-i, ABSOLUTE, MOTO, EMPhAtiC, 5GNOW, SOLDER, METIS and ADEL. The project standardization priorities are specifications that should be pushed to standards in order to enable real-world deployment of their proposed solutions.

4.1 FP7 CRS-i

4.1.1 CRS-i research directions in the CR domain

The main objective of the Coordination Action CRS-i (Cognitive Radio Standardization initiative) [1] is to coordinate and support FP7 projects and to facilitate the exploitation of their results by establishing a concentrated approach to Cognitive Radio Systems standardization.

Moreover, CRS-i aims to extend and coordinate standardization activities of the concluded cognitive radio projects FP7 COGEU, FP7 QoSMOS, FP7 SACRA and FP7 OneFIT beyond the projects lifetime. Within this perspective, CRS-i has extended the standardization activities of the concluded projects QoSMOS, COGEU, SACRA and OneFIT towards three main standardization streams: TV White Spaces (TVWS) PHY and MAC; Device-to-Device (D2D) communications and Licensed Shared Access (LSA).

4.1.2 CRS-i standardization priorities

CRS-i consortium has agreed that the focus of the project will be concentrated in the following standardization activities:

- ETSI RRS WG1:
    - ETSI TS 103 145 “System Architecture and High Level Procedures for Coordinated and Uncoordinated Use of White Spaces”
    - ETSI TS 103 143 “System Architecture for Information Exchange between different Geo-Location Databases (GLDBs) enabling the operation of White Space Devices (WSDs)
    - ETSI TS 103 154: System requirements for operation of Mobile Broadband Systems in the 2300 MHz – 2400 MHz band under Licensed Shared Access (LSA) regime
    - ETSI TS 103 235: System Architecture and High Level Procedures for operation of Licensed Shared Access (LSA) in the 2300 MHz-2400 MHz band
- IEEE DySPAN-SC:
    - IEEE P1900.7 “Radio Interface for White Space Dynamic Spectrum Access Radio Systems Supporting Fixed and Mobile Operation”
- 3GPP Rel12 (RAN2 group) “Proximity Service work item" and follow-up in Rel13 (SA1 & SA2 groups)

4.2 FP7 ABSOLUTE

4.2.1 ABSOLUTE research directions in the CR domain

The main objective of the ABSOLUTE project (Aerial Base Stations with Opportunistic Links for Unexpected & Temporary Events) [16] is to design and validate an innovative rapidly deployable network architecture which is resilient and capable of providing broadband multi-service, secure and dependable connectivity for large coverage areas affected by large scale unexpected events (or disasters) leading to the partial or complete unavailability of the terrestrial communication infrastructure. The project will demonstrate the high capacity, low-latency and coverage capabilities of LTE-A solutions adapted for broadband emergency communications within disaster relief scenarios through flexible 4G base stations embedded on aerial platforms and terrestrial portable units.

The functional elements and the respective network architecture are based on the user/stakeholder requirements and the European positioning for broadband spectrum strategy for PPDR (Public Protection and Disaster Relief) systems. Device to Device communication is considered for the scenario where network coverage is temporarily lost. Figure 4 provides an overview of the ABSOLUTE system architecture.

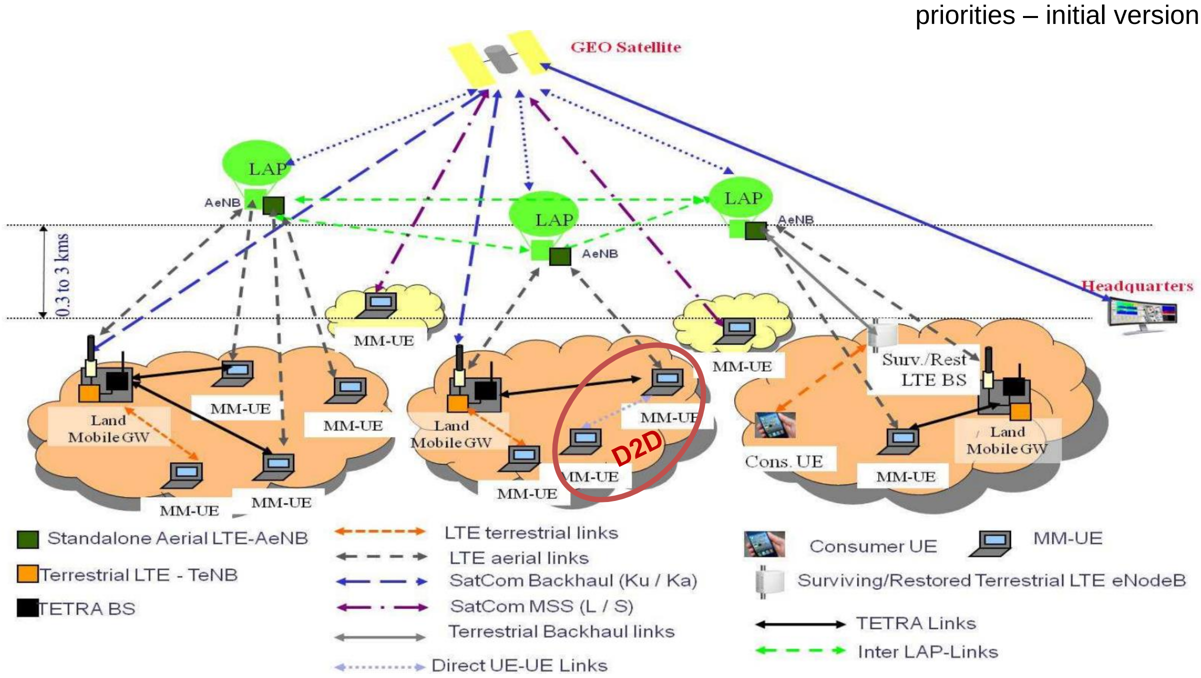

Figure 4 ABSOLUTE architecture [16].

ABSOLUTE scenarios are characterised by a highly dynamic network topology and by the presence of different radio access technologies with very different characteristics (TeNodeB – Terrestrial eNodeB, AeNodeB – Aerial NodeB, TETRA, narrowband S-band satellite links) in terms of coverage, data rate and latency. Several key issues including dynamic spectrum management for rapid network configuration and interoperability, dynamic topology management and mobility considerations are addressed by the project.

The ABSOLUTE project aims to develop a LTE-based solution for temporary PPDR use and considers the possibility of dynamic use of spectrum resources between commercial and public safety users for disaster relief. Operation in frequency bands used by permanent LTE networks would require dedicated solution to allow sharing with these networks.

ABSOLUTE is investigating Spectrum Awareness and Cognitive Dynamic Spectrum Access techniques:

- Spectrum Awareness:
  - The overall spectrum awareness framework has been built considering both REM (Radio Environment Maps) and spectrum sensing approaches
  - Two-phase spectrum awareness for Roll-out and In-service phases
  - Initial Implementation Plan of ABSOLUTE Cognitive Mechanisms to LTE Systems
- Cognitive Dynamic Spectrum Access:
  - Opportunistic links in S-Band
  - Dynamic coexistence of satellite and AeNBs in S-band.

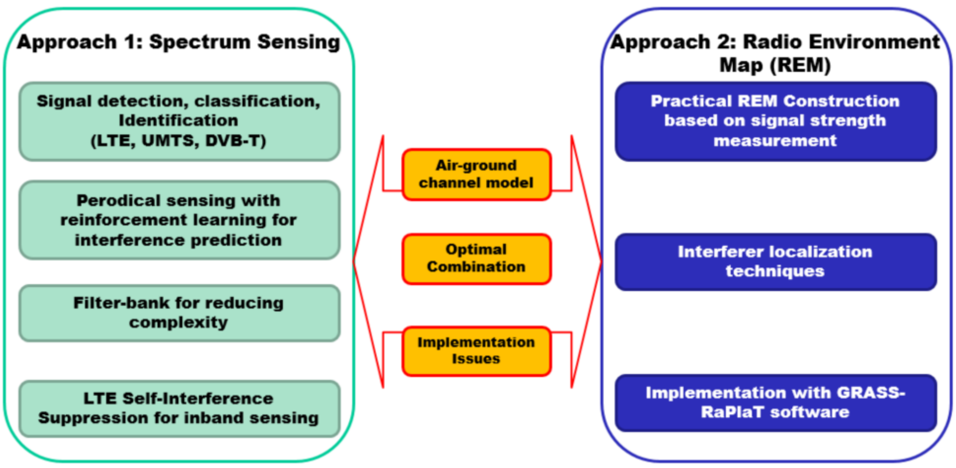

Figure 5 Spectrum Awareness for Disaster Recovery and Event Servicing – technologies under investigation.

4.2.2 ABSOLUTE standardization priorities

ABSOLUTE project has identified several standardization organizations (3GPP, ETSI, IETF and IEEE) and the regulatory body CEPT as relevant targets for the project dissemination (Figure 6).

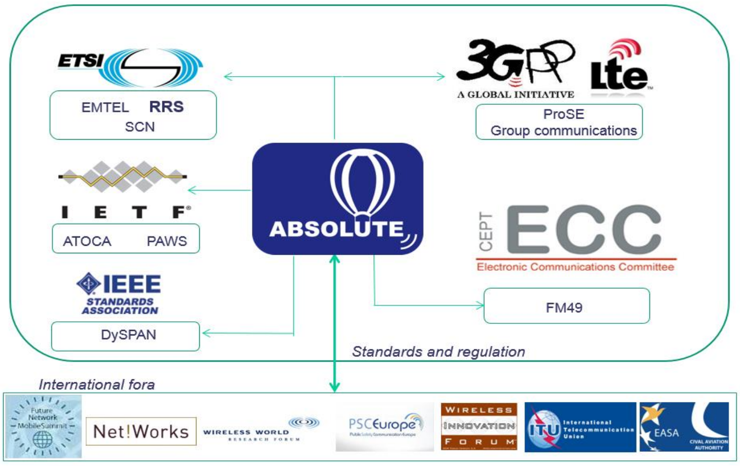

Figure 6: ABSOLUTE target standards and regulation.

Device to Device (D2D) communication and discovery, as a support for so-called Proximity Services (or ProSe) have been considered by 3GPP for use in commercial scenarios (e.g. for providing higher data rate or reuse of radio resources locally, based on proximity of communicating users) and in scenarios related to public safety and critical communications (3GPP TR 36.843 [17]) , see Figure 7.

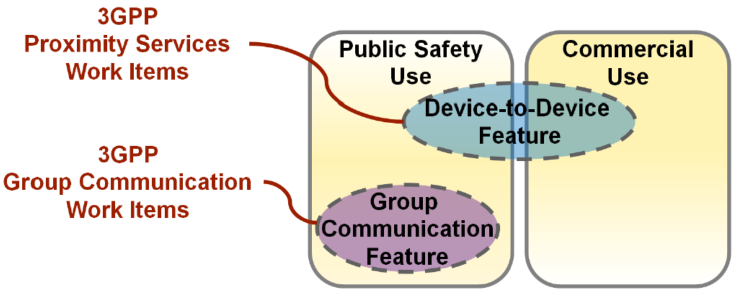

Figure 7: 3GPP Proximity Services and Group Communication Work Items.

<u>Scenarios</u>
ABSOLUTE's team provided inputs to 3GPP SA1 with regard to requirements on ProSe for Public Safety. Public Safety requirements, from ABSOLUTE or other 3GPP members (e.g. US Dept of Commerce), have been captured in TS 22.278. From the scenario point of view, ABSOLUTE work is compatible with the work in 3GPP.

<u>System architecture & Protocols</u>
At this stage, it is not clear whether the system architecture considered by ABSOLUTE for the D2D aspects is compatible with the road taken by 3GPP in 2013/14 for Rel12. However given that ABSOLUTE is fundamentally a 3GPP infrastructure, the system is agnostic with regard to the D2D air interface to be used, meaning that both WLAN and the new 3GPP interface could be used. The compatibility with 3GPP seems unavoidable: Therefore ABSOLUTE project will have to consider how to secure their solution with regard to 3GPP choices.

In this context, the ABSOLUTE project has contributed to 3GPP RAN WG1 in the D2D study item with public safety services requirements, scenarios and evaluation methodology. In particular ABSOLUTE has contributed to 3GPP with scenarios where network coverage are temporarily lost and direct D2D communication has to be provided [18].

The ETSI RRS WG4 Terms of Reference (ToR) have been recently refined in order to align with Objective C/Phase 1 of the EC mandate M512. Therefore, RRS WG4 will define Use Cases, Requirements, Architectures and Interfaces for exploiting synergies among commercial, civil security and military domains and more specifically. ABSOLUTE is interested to contribute to ETSI RRS WG4.
The ABSOLUTE standardization activities are led by Thales Communications & Security and Nomor Research GmbH.

4.3 FP7 MOTO

4.3.1 MOTO research directions in the CR domain

The MOTO project, "Mobile Opportunistic Traffic Offloading" [26], is investigating a traffic offloading architecture that exploits in a synergic way a diverse set of offloading schemes, including offloading from cellular to other wireless infrastructures (such as Wi-Fi), and also offloading to multi-hop ad hoc communications between users devices, through opportunistic Device-to-Device (D2D) communications. The offloading scenarios considered for the MOTO systems are all based on direct device-to-device communications, with two main categories:

- Offloading by smartphone-to-smartphone communications;
- Offloading by vehicle-to-vehicle communications.

The scenarios are considering the following reasons/opportunities for offloading, web caching, network congestion, content dissemination, in various situations of large (stadium, museum,…) or small crowd (local social network…).

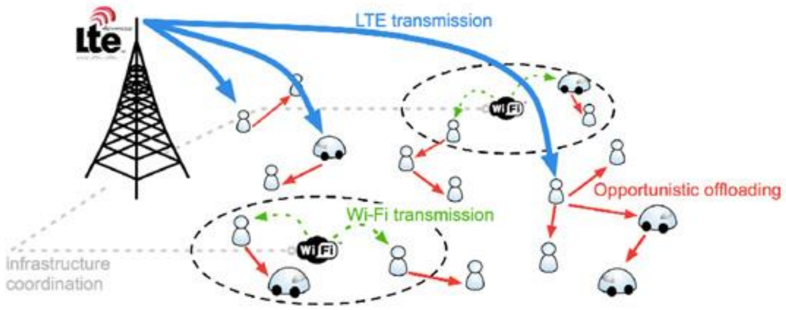

Figure 8: MOTO scenarios [26].

The chosen architecture is an "over-the-top" one, where all new functionalities are provided to the mobile users as an extra layer using the data/user plane offered by 3GPP or WiFi networks. MOTO has built its architecture on some expected provision of an "Infrastructure API" by the 3GPP and WiFi networks: they have not yet detailed such API, except for the requirement to have some "Network Status" information, typically about remaining local capacity or local congestion situation, provided by the network to the MOTO platform.

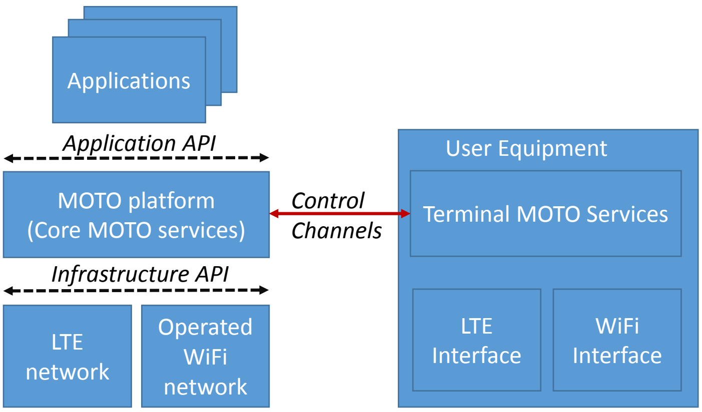

Figure 9: MOTO reference architecture [26]

MOTO also introduces control channels to carry information and control between the platform and the concerned user equipment, typically to support the exchange of security data (authentication) and of offloading orders. MOTO considers WiFi Direct (for the smartphone-based scenarios) or 802.11p (for the vehicle-based scenarios) as candidate for direct device-to-device communications. At this stage, it is not clear if MOTO intends to develop and detailed further the Infrastructure API or the Control Channels.

4.3.2 MOTO standardization priorities

The technology developed by MOTO project is linked to both 3GPP (as offloading 3GPP cellular networks is the purpose of the developed system) and IEEE/WiFi Alliance (as WiFi networks and WiFi Direct is the D2D technology) standards. In the following, we'll consider the 3GPP target.

Scenarios
The smartphone-based scenarios considered by MOTO are compatible with one of the 3GPP scenario for Release 12, namely "Network Offloading via WLAN ProSe Communication" [TR 22.803, section 5.1.13], so, from this point of view, theoretically, MOTO solution could be promoted in 3GPP. However, the MOTO vehicle-based scenarios are not part of 3GPP scenarios.

System architecture & protocols
The over-the-top architecture chosen by MOTO seems to be compatible with the system architecture designed by 3GPP, with the MOTO Core Services platform considered as an extension of the ProSe function as currently defined. The potential additional requirements from MOTO would be on interfaces PC2, PC3, PC4a and PC4b.

Moreover, these interfaces, just starting to be worked on by the CT Working Groups of 3GPP, are unlikely to support the "Network Status" information about remaining local capacity, which is the one requirement from MOTO identified at this stage of the project: an additional interface with the eUTRAN or the O&M system may likely be needed.

The computation/provision of congestion information has already been a topic for non-D2D Work Item in 3GPP, like the suspended UPCON and dos have impacts on 3GPP-internal interfaces. Besides, in 3GPP, the ProSe Function is considered part of the EPC, i.e. of the 3GPP network operator's domain where the MOTO architecture seems to consider different operators for the LTE network(s), the WiFi network(s) and the MOTO system: any action towards standardization would have to take this into account. The standardization activities are led by Thales Communications & Security.

4.4 FP7 EMPhAtiC

4.4.1 EMPhAtiC research directions in the CR domain

The EMPhAtiC project [13] addresses the need to upgrade the PMR/PPDR narrowband networks (TETRA, TETRAPOL, and others) towards supporting broadband data communications services. The new required capacity can be achieved in two complementary ways: by obtaining new frequency bands for PPDR data services and by fitting a novel broadband data service within the scarcely available spectrum devoted to PMR systems. To satisfy the growing demands, both directions actually have to be followed. The EMPhAtiC project focus on the latter approach, which can be seen as a very challenging evolution path, but also the most realistic opportunity to benefit from the advantages of latest developments in multicarrier waveforms and related signal processing techniques. One of the major issues is being able to introduce new broadband data services within the current frequency allocation, in coexistence with current PMR/PPDR systems. The advanced waveforms and signal processing techniques to be developed and validated find applications in various other scenarios of flexible spectrum usage and cognitive radio.

At the waveform level, the main issue is the poor spectral containment of the Cyclic Prefix – Orthogonal Frequency Division Mutliplex (CP-OFDM) subcarriers, leading to high side lobes of the modulated OFDM spectrum, which creates interference to neighbouring frequencies and is thus problematic in the coexistence scenario to be addressed. Additionally, high flexibility is needed to utilize effectively the variable spectral gaps between different narrowband users. Furthermore, the radio implementations have to support non-contiguous spectrum allocations, at least on the base-station side. Multicarrier modulation is a natural approach to address the latter issues, but increased flexibility is of significant interest, e.g., in the form different subcarrier spacing for different users.

The EMPhAtiC approach is to develop an efficient and highly flexible/variable filter-bank processing structure. Such filter-banks could accommodate simultaneously different modulation formats with adjustable centre frequencies and bandwidths, possibly with non-equidistant subchannel spacings, and they could be used for the modulation, demodulation and frequency-domain equalization of different Filter Bank Multi Carrier (FBMC) and Filter Bank Singe Carrier (FBSC) waveforms, even simultaneously. Regarding the coexistence between narrow-band and broad-band PMR systems, such a flexible filter bank could also provide in an efficient way the functionality of transmitter and receiver channelization for legacy PMR signals. The standardization activities are led by CASSIDIAN-EADS.

4.4.2 EMPhAtiC standardization priorities

The main objective of EMPhAtic standardization strategy is to promote as much as possible the advantages and main benefits of the adoption of filter-bank and enhanced OFDM approaches for future standard evolutions. This work will mainly concern working group ETSI TETRA WG4 in which the EMPhAtic partner CASSIDIAN-EADS takes part, but could also be seen in 3GPP context, as a very first set of topics to be discussed. TETRA WG4 is in charge of SRDoc Broadband, which is the system reference document describing and specifying the frequency needs for Broadband PMR for PPDR.

The ETSI RRS WG4 Terms of Reference (ToR) have been recently refined in order to align with Objective C/Phase 1 of the EC mandate M512. Therefore, RRS WG4 will define Use Cases, Requirements, Architectures and Interfaces for exploiting synergies among commercial, civil security and military domains and more specifically. EMPhAtiC is interested to contribute to ETSI RRS WG4.

EMPhAtiC project is conscious that the introduction of new schemes, as FBMC, in LTE will not be easy in the current standardization process because 3GPP stakeholders are not willing to change the general structure of the LTE system (OFDM based). An opportunity could exist with the introduction with new modes without insuring backward compatibility in Rel. 13. The standardization activities are led by CASSIDIAN-EADS.

4.5 FP7 5GNOW

4.5.1 5GNOW research directions in the CR domain

5GNOW [14] addresses the use of non-orthogonal waveforms for 5G scenarios. 5GNOW states that the underlying design principles –synchronism and orthogonality– of the PHY layer of today's cellular technology constitute a major obstacle for further evolutions of 3GPP standards in order to increase capacity and serve the expected scenarios. 5GNOW elaborates on cases such as:

- the emergence of machine type traffic (MTC) stemming from the boom of the IoT and the sporadic traffic it generates. MTC should be able to awake only occasionally and transmit their message right away only coarsely synchronized. By doing so MTC traffic would lower uplink data signalling and thus alleviating synchronism requirements. This could significantly improve operational and lifetime of autonomous MTC nodes.
- spectral fragmentation induced by spectrum harvesting and potentially dynamically allocated channels would also benefit from less stringent requirements on orthogonally, thereby fostering better spectrum usage.
- real-time constraints, such as the ones of the so-called "tactile internet" would benefit from non-orthogonal waveforms as those PHY do not require lengthy cyclic prefixes and guard intervals.
- cooperative multipoint (COMP) would enable several BS to address a mobile more easily if a certain level of synchronicity is tolerated.

The 5GNOW scenarios are illustrated in Figure 10. The right hand scenario (green area) shows the use case dedicated to "flexible fine grained sharing of fragmented spectrum", which is based on flexible and dynamic spectrum access concepts. In this scenario, two of the non-orthogonal PHY which are being studied in 5GNOW, namely FBMC and Generalized Frequency Division Multiplexing (GFDM), are derived from the FBMC and GFDM air interfaces studied in the QoSMOS project.

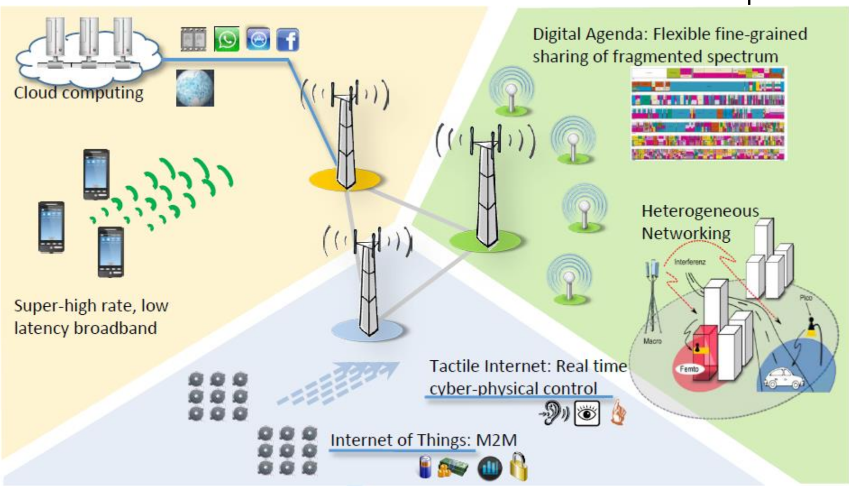

Figure 10: 5GNOW scenarios [14].

4.5.2 5GNOW standardization priorities

5GNOW studies the evolutions of cellular systems and suggest the use of non-orthogonal waveforms. The project focusses on physical layer aspects. The project claims that coexistence, interference management can greatly benefit from the use of non-orthogonal waveforms. Concretely the 5GNOW FBMC waveform has impacted the IEEE P1900.7 White Space Radio Working Group (from the DySPAN-SC serie).

Moreover, 5GNOW has identified an opportunity in 3GPP for launching a study item for non-orthogonal waveforms and transmission schemes in Rel. 13 that will be initiated in 2015. The standardization roadmap for 5G is shown in Figure 11. The standardization activities are led by Alcatel Lucent and CEA-LETI.

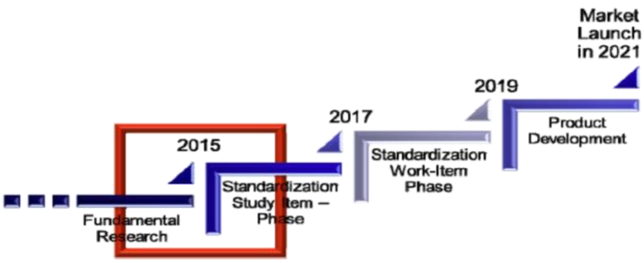

Figure 11: 5G standardization roadmap.

4.6 FP7 SOLDER

4.6.1 SOLDER research directions in the CR domain

The capability of having high data rate along with flexibility in spectrum usage for wireless communications can be met by cognitive radio application in beyond 4G mobile wireless communications. Although cognitive radio has been discussed a lot in last years as a key technology for dynamic spectrum management within IEEE type of systems, it seems now that it could be an efficient solution for bandwidth expansion and thus improving the capacity, throughput and performance in general for next generation wireless communication systems.

The goal of SOLDER (Spectrum OverLay through aggregation of heterogeneous DispERsed Bands) [15] is to develop a new spectrum overlay technology, which will provide the efficient aggregation of non-continuous dispersed spectrum bands licensed to heterogeneous networks (HetNets) and heterogeneous Radio Access Technology (h-RATs). A key enabling technique which promises further improvement in data rates is Carrier Aggregation (CA). Intra-band and inter-band carrier aggregation, in a continuous or a non-continuous fashion, have been proposed within the 3GPP standardization body for LTE-Advanced (LTE-A). Cross-carrier scheduling is also specified through dynamic scheduling on different component carriers. LTE-A has been specified to support all types of CA using several transmission bandwidths for all band combinations.

SOLDER's main objective is to design advanced physical and upper layer techniques, such as diversity, link adaptation and radio resource management, which will be able to handle the aggregation of non-continuous and dispersed bands (i.e. HetBands) extending thereby the 3GPP functionality. More specifically, frequency and subcarrier diversity, multi-channel link adaptation and multidimensional radio resource and inter-carrier interference management will be developed and demonstrated over such a new heterogeneous and wideband fading environment.

4.6.2 SOLDER standardization priorities

SOLDER expects to provide a number of contributions to standards in order harmonise the industrial adoption and understanding of related technologies. Particular targets include the IEEE 1900 series standards and IEEE Dynamic Spectrum Access Networks Standards Committee (DySPAN-SC) in general, as well as the likely ETSI Reconfigurable Radio Systems (ETSI-RRS) standards, as well as an aspiration the 3GPP LTE-Advanced standards development process although that presents a number of challenges because of the lack of 3GPP stakeholders in the project consortium and the forward looking nature of the project. The SOLDER standardization activities are led by King's College London.

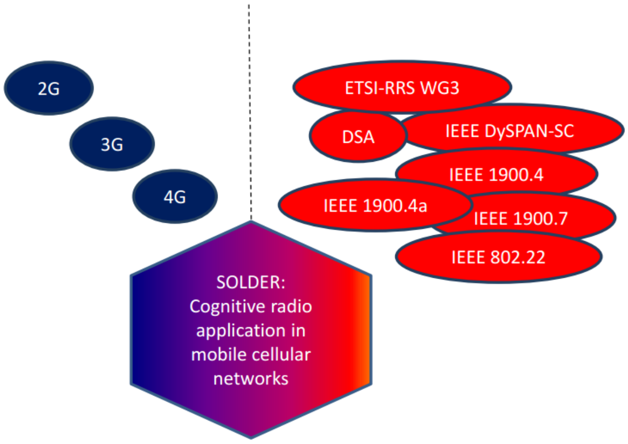

Figure 12 SOLDER's concept: bridging the two worlds of cellular and cognitive radio.

4.7 FP7 METIS

4.7.1 METIS research directions in the CR domain

The analysis of METIS (Mobile and wireless communications Enablers for the Twenty-twenty Information Society) [19] clearly highlights the importance of making new spectrum usage options available for the next generation of mobile systems. Not only more spectrum and more efficient spectrum usage concepts are required but the broader range of METIS application requirements will also result in new challenges on spectrum engineering with respect to guaranteeing co-existence, compatibility, and coverage.

METIS has developed the concept of "Spectrum Sharing Tool Box" [20] with the aim to enable the choice of sharing techniques on demand when a specific sharing situation is encountered. When required the relevant sharing solutions will be turned on and smooth coexistence with other systems will be ensured. The inclusion of all proposed sharing tools in the toolbox is required in order to allow for operation and sharing spectrum in a wide range of regulatory frameworks.

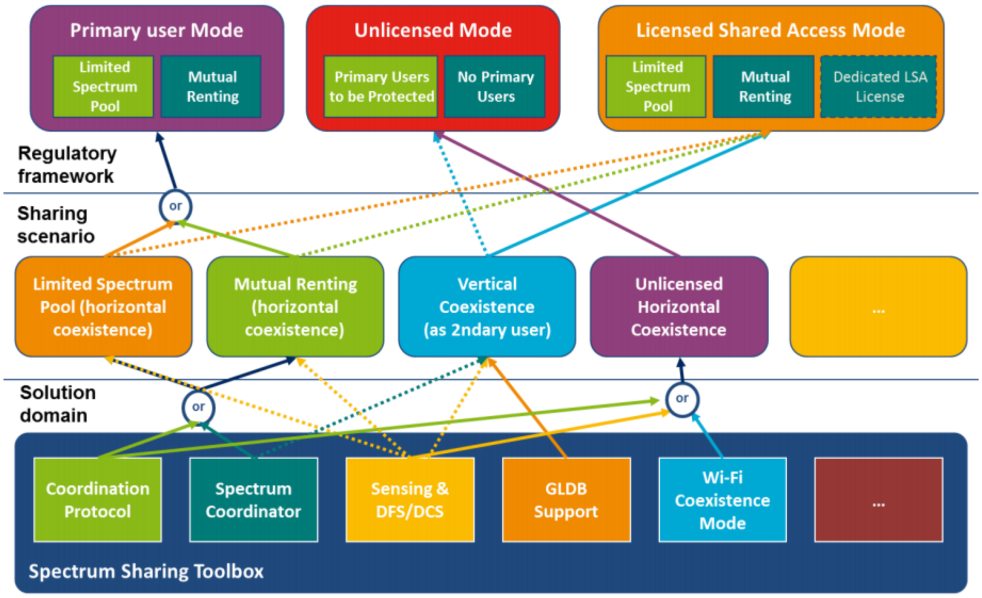

Figure 13: The METIS spectrum sharing toolbox. Solid arrows illustrate "required" relations (e.g., needed tools or scenarios which are necessary parts of a regulatory framework) whereas dotted arrows illustrate "optional" or "possible" relations [20].

The METIS "Spectrum Sharing Tool Box" encompasses the Licensed Shared Access (LSA) mode as a promising access model in which a primary license holder (incumbent) would grant spectrum access rights to one or more other users which can use the band under specific service conditions. The details of the spectrum usage would be subject to an individual agreement and permission by the National Regulatory Authority. The LSA concept was originally proposed by an industry consortium under the name "Authorized Shared Access" (ASA). The Radio Spectrum Policy Group (RSPG) and the European Commission largely adopted the concept but renamed it to LSA.

4.7.2 METIS standardization priorities

The current standardization priority related with CR is the architecture work for LSA in ETSI RRS WG1. This is important to get a high acceptance and to be upward compatible to future evolution. Besides that, standardization activities in IEEE 802.11, IEEE 802.22, IEEE DySPAN-SC, and 3GPP are related to METIS, but are (currently) not in the main scope. The METIS standardization activities related with LSA are led by NSN.

4.8 FP7 ADEL

4.8.1 ADEL research directions in the CR domain

The main objective of ADEL (Advanced Dynamic Spectrum 5G mobile networks Employing Licensed shared access) project [21] 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)

4.8.2 ADEL standardization priorities

The project showed interest in contribute to ETSI RRS and was presented in the ETS RRS#24 meeting. The term LSA is used by ADEL in a slightly different another context than in ETSI RRS, e.g. sensing is investigated as well which would more fit to TV White System systems. It requires further investigation to identify in which Working Group within ETSI RRS the ADEL project could be relevant. A successor of the LSA specifications in ETSI TC RRS (with a currently limited scope) may be appropriate. The standardization activities are led by Intel.

4.9 FP7 CoRaSaT

4.9.1 CoRaSaT research direction in the CR domain

The main aim of the CoRaSat project is to investigate, develop and demonstrate cognitive radio techniques in satellite communication systems for spectrum sharing and to prove its outcomes as support and guidelines for the definition of regulatory, standardization, and technology frameworks for the exploitation of cognitive radio in support of the Digital Agenda for Europe [1].

To achieve its goals, the project has identified seven challenging Satellite Communication (SatCom) scenarios, which correspond to various frequency ranges of interest in the Ka-, Ku-, C-, and S-bands. To assess the potential of more efficient utilization of spectrum in the SatCom context, particular attention is paid to specific use case scenarios where satellite services are provided as cognitive (new entrant) services, whereas the incumbent services can be either terrestrial or satellite [12].

The scenarios are related to specific frequency ranges within the given frequency bands, to which different regulatory conditions apply. Also, both downlink and uplink satellite link directions, as well as both Geostationary Satellite Orbit (GSO) and Non-Geostationary Satellite Orbit (NGSO) are considered. Moreover, both fixed and mobile satellite terminals are taken into account. The cognitive radio techniques considered by CoRaSat are summarized in Table 4-1.

Table 4-1: Overview of CoRaSat candidate techniques

Cognitive Techniques	**Interweave**		**Underlay (UL)**	**Overlay (OL)**
	Databases	**Spectrum Sensing**		
Cognitive Information	Geolocation data	Power Spectral Density (PSD)	Channel State Information (CSI)	CSE and Primary data
QoS Constraints	Access Time	Detection Probability	Interference Threshold	Rate limit threshold
CoRaSat Challenges	Wide satellite footprint DB security and integrity	Weak signal detection LoS interference	Resource optimization problem LoS slow-fading channel	Asynchronous arrivals of signals Primary-secondary coordination
CoRaSat Candidate Techniques	Efficient database and access techniques Beaconing techniques Localization assisted techniques	Spectral shaping Polarization sensing DoA sensing Cooperative sensing Distributed sensing	Power allocation Radio Resource Management Beam steering Polarization-aware techniques Waveform detection Interference floor	Relaying Known interference pre-cancelation Rate splitting

4.9.2 CoRaSaT standardization priorities

The CoRaSat project proposed a new work item in ETSI SES SCN (Satellite Earth Stations and Systems - Satellite Communication and Navigation) working group on “Cognitive radio techniques for Satellite Communications” (DTR/SES-00343). The work item aims at proposing and analysing SatCom architectures implementing cognitive radio techniques for different scenarios where the SatCom service shall not create any harmful interference to another terrestrial or satellite service entitled to use the same spectrum on a primary basis. The work item was approved by the ETSI SES TC and the CoRaSat team is contributing to the preparation of the ETSI System Reference document. The standardization activities are led by Thales Alenia Space.

5 Standardization synergies between FP7 projects in CR

Table 5-1 summarizes the project's research directions and the standardization working groups that each project wants to target. With this information is possible to identify standardization synergies between FP7 projects working on CR and spectrum related issues. Figure 15 shows the project schedule and the time window to exploit opportunities for cooperation for the target standardization activities.

Table 5-1: Mapping of project research directions and standards.

Project	Project's research directions in CR	Target standard	Partners involved in CR standardization activities
CRS-i	White spaces access	ETSI RRS WG1 IEEE P1900.7	IT and CEA-LETI
	Licensed Shared Access (LSA)	ETSI WG1	NSN
	D2D communications	3GPP RAN2 group "Proximity Service work item" and follow-up in Rel13 (SA1 & SA2 groups)	NSN and NTUK
ABSOLUTE	Cognitive Dynamic Spectrum Access - Spectrum Awareness; Sensing and REM (Radio Environment Map)	ETSI RRS WG4	Thales Communications & Security; Nomor Research GmbH; CREATNET
	D2D communication and discovery for public safety scenarios	3GPP LTE RAN (ProSe)	
MOTO	D2D communication and discovery for traffic offloading scenarios	3GPP LTE RAN (ProSe)	Thales Communications & Security
EMPhAtic	Non orthogonal waveforms (PHY); Filter-bank waveforms for Broadband public safety.	ETSI TETRA WG4 ETSI RRS WG4 3GPP LTE RAN1 (Rel.13)	CASSIDEAN-EADS; Thales Communications & Security;
5GNOW	Non-orthogonal waveforms (PHY); Filter-bank waveforms for 5G scenarios	IEEE P1900.7 (DySPAN-SC)	CEA-LETI
		3GPP LTE RAN1 (Rel.13)	ALCATEL-LUCENT
SOLDER	Non-continuous Carrier Aggregation; Radio Resource Management; PHY and upper layer techniques	IEEE 1900 (DySPAN-SC) 3GPP LTE	King's College London
METIS	Licensed Shared Access (LSA)	ETSI RRS WG1 (LSA)	NSN
ADEL	Licensed Shared Access (LSA); Databases, spectrum sensing	ETSI RRS WG1 (LSA)	Intel
CoRaSaT	Databases, spectrum sensing	ETSI SES SCN	Thales Alenia Space

Although the projects in general have a diverse scope of standardization targets, CRS-i has identified several opportunities for a concentrate effort towards standardization as identified below:

- Trigger a new Study Item in 3GPP on Non Orthogonal Waveforms: EMPhAtic and 5GNOW
- Joint contributions to 3GPP LTE RAN on D2D (ProSe): ABSOLUTE and MOTO
- Joint contributions to LSA system architecture work in ETSI RRS WG1: CRS-i, METIS and ADEL
- Joint contributions to White Spaces technologies in DySPAN-SC: CRS-i, 5GNOW and SOLDER
- Joint contributions to ETSI RRS WG4 : Use Cases, Requirements, Architectures and Interfaces for exploiting synergies among commercial, civil security and military domains and more specifically (Objective C of the EC Mandate M512): ABSOLUTE and EMPhAtic

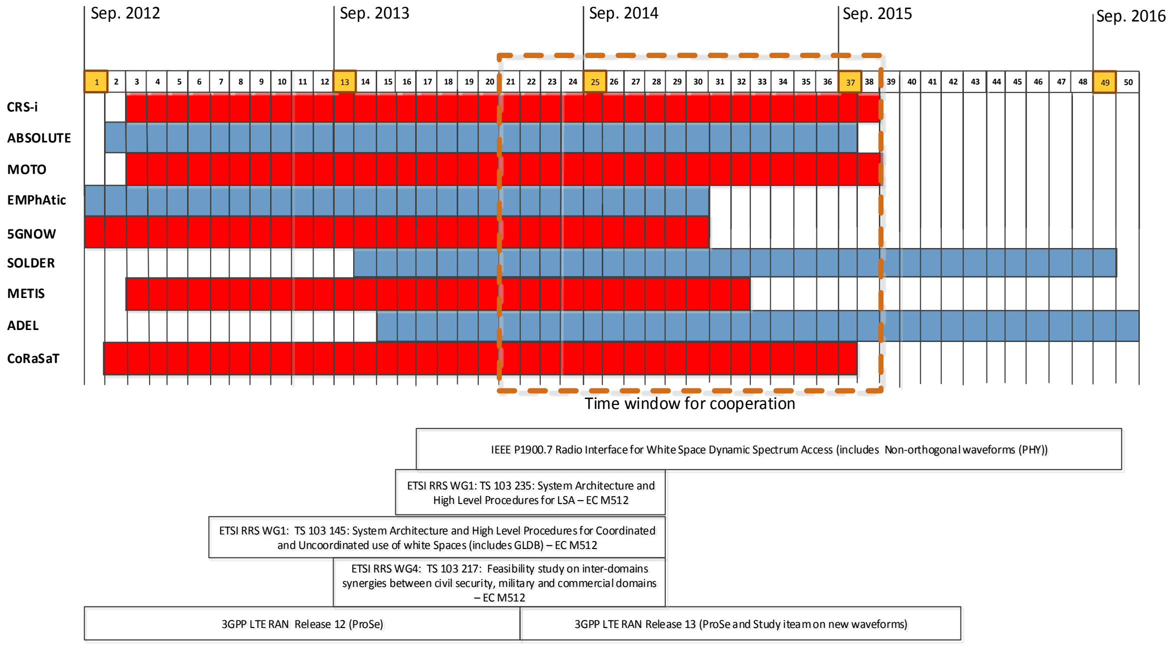

Figure 14: Project schedule and time window to exploit opportunities for cooperation (the schedule of the ETSI standards work items is as per 30 April 2014 as is likely to be extended).

6 Trends in spectrum research and impact on standards evolution

In this chapter we identify research trends in the area of cognitive radio, dynamic spectrum access and coexistence issues and we discuss future directions for standardization.

MAC for non-orthogonal waveforms

Suitable MAC mechanisms able to exploit the superior characteristics of non-orthogonal waveforms over legacy OFDM solutions is an emerging research area that in the future needs to be reflected in the relevant standards (e.g. IEEE P1900.7).

LTE in Unlicensed Band (LTE-U)

The idea of deploying LTE in unlicensed bands was recently proposed by QUALCOMM [27], particularly focusing on the 5GHz band, which is currently used mostly for WiFi. According to a document (RP-131635) submitted to 3GPP, the proposal is to deploy LTE as Supplemental Downlink (SDL) in 5725-5850 MHz in USA, with the PCell (Primary Cell) always operating on a carrier in a licensed band. Verizon has also submitted a Work Item Proposal (RP-131680) to introduce the new band for SDL usage. There's also a Study Item proposal from Ericsson (RP-131788) to study the modifications necessary to the LTE radio standard. Features for coexistence and protection of WiFi needs to be developed and standardized.

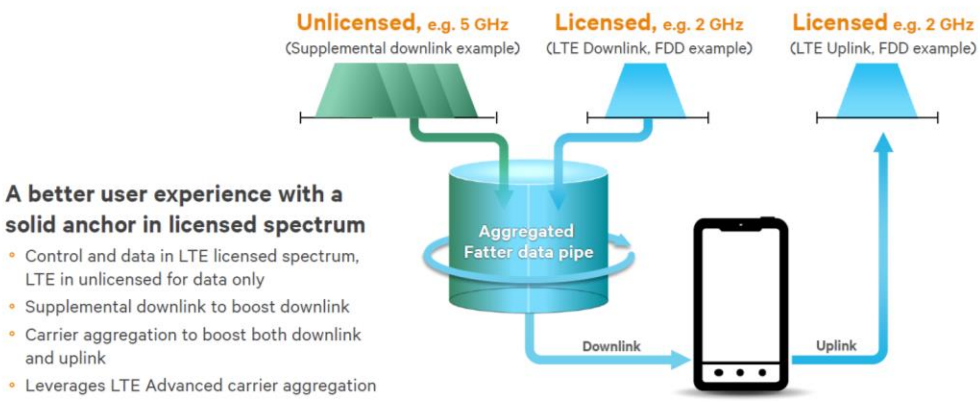

Figure 15: LTE Advanced in unlicensed spectrum for additional downlink capacity [27].

Harms Claim Threshold

Radio operation has traditionally been regulated solely based on using limits on transmitters, with few if any explicit constraints on receivers. Harm claim thresholds are the interfering signal levels that must be exceeded before a radio system can claim harmful interference (Figure 16). While they are used to include receivers in spectrum management, harm claim thresholds are not receiver standards or receiver performance mandates: operators and manufactures are free to determine how to build and deploy receiving systems that can tolerate allowed interfering signals.

The FCC Technological Advisory Council has recommended the use of this approach in a recent white paper [28]. The first step would be for a regulator to develop an interference limit policy framework that will include criteria and methods for supplementing Harm Claim Thresholds with receiver performance requirements like receiver self-certification and standards, enforcement mechanisms, e.g. the use of measurement vs. modelling to resolve disputes.

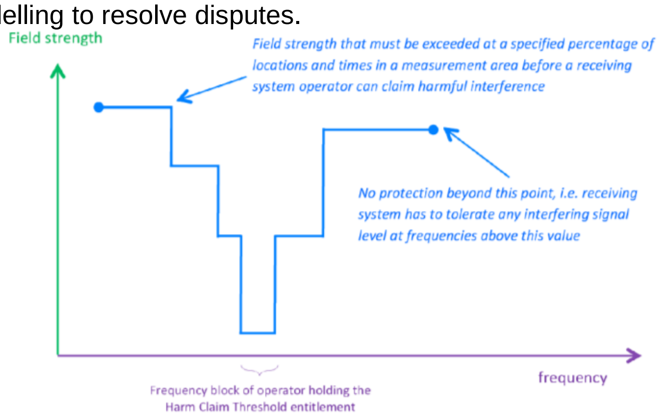

Figure 16: Harms Claim Threshold concept [29].

Security architecture for cognitive radio in general and for LSA specifically

Currently, the LSA architecture, especially the question of ownership and location of the LSA repository and the LSA controller(s) is under discussion. A very important part of future considerations, including research and standardization, will be the security architecture for cognitive radio in general and for LSA specifically. First steps to this have already been made in ETSI RRS (with the proposal of a security related specialist group).

Network interfaces and protocols for D2D communications

For Rel.12, 3GPP had to restrict the set of features to be specified, in order to secure the schedule of the specifications. The (most probably) final set is:

- ProSe Discovery (this is based on a new air interface between UEs)
- ProSe Communication 1-to-Many (ditto)
- ProSe UE-to-NW relay solution with no RAN impact (ditto)
- EPC support for WLAN (this is using the WLAN interface between UEs)

This means that the following features are left-overs:

- ProSe Communication 1-to-1 (over the new air interface)
- ProSe UE-to-NW-relay solution with RAN impact (for enhanced performance/functionality)
- UE-to-UE-relay (multi-hop)
- Service continuity (handovers between UEs, between UE and eNB)
- Discovery: Interaction with 3rd party apps & UE terminal apps.

Besides, the work in 3GPP for Release 12, after an initial focus on system architecture and definition of the new air interface between UEs, is now starting on network interfaces and protocols in RAN CT groups, where Rel. 13 work is starting on requirements.

For ABSOLUTE and MOTO, as already mentioned, there are some opportunities and actually needs in 3GPP to ensure the compatibility of their solutions with the ProSe specifications, either by adapting the project's solution or by promoting their detailed technical requirements to the relevant WG (most probably CT WGs) in Rel12.

7 Conclusion

This position paper identifies and describes in a consolidated manner the research and standardization activities in cognitive radio in a European level. This is a fundamental step that the CRS-i consultancy service took towards reaching its main goal, i.e., to strengthen the position of FP7 projects in standardization bodies related to cognitive radio, and to facilitate the pull through of European project outcomes.

The main outcomes of this deliverable are summarized as follows:

The evolution of the EU spectrum policy is detailed. More specifically, the RSPP and CEPT responses to the identified need for efficient solutions in order to accommodate the growing demand for data traffic were described. The solutions discussed include the identification of additional spectrum bands that can be allocated for mobile communications, as well as the efficient support of spectrum sharing through LSA.

The ETSI response to the European Standardization Mandate for Reconfigurable Radio Systems was described. A summary of the respective Mandate and its three main objectives was provided, while the ETSI TC RRS work under Objectives A and C was described.

A consolidated view of the currently scattered knowledge standardization groups and work items in different aspects of the area of CR was provided. An updated description of the recent and planned standardization efforts in ETSI, IEEE and IETF was provided, with the aim to facilitate the FP7 research projects' understanding of the diverse structural aspects of CR standardization in a global level.

The FP7 projects research direction in the CR area and related standardization priorities were identified for the CRS cluster projects: CRS-i, ABSOLUTE, MOTO, EMPhAtiC, 5GNOW, SOLDER, METIS and ADEL. From this analysis a list of synergies and opportunities for cooperation between FP7 projects in the standardization area were identified:

- A new Study Item in 3GPP (Rel.13) on Non Orthogonal Waveforms: EMPhAtic and 5GNOW;
- Joint contributions to 3GPP LTE RAN on D2D (ProSe) to ensure the compatibility of the proposed solutions with the ProSe specifications: ABSOLUTE and MOTO;
- Joint contributions to LSA system architecture work in ETSI RRS WG1: CRS-i, METIS and ADEL;
- Joint contributions to White Spaces technologies in DySPAN-SC: CRS-i, 5GNOW and SOLDER;
- Joint contributions to ETSI RRS WG4: Use Cases, Requirements, Architectures and Interfaces for exploiting synergies among commercial, civil security and military domains and more specifically (Objective C of the EC Mandate M512): ABSOLUTE and EMPhAtic.

Finally, an analysis of recent trends in the area of CR and spectrum coexistence aspects that may have significant impact on standards' evolution is provided.

As a next step, the CRS-i Coordination Action will communicate this gained knowledge on research directions and opportunities to the CRS cluster projects. The main aim of this is to further enhance their active participation in the physical meetings of the targeted standardization groups as well as their collaboration with other cluster projects with similar priorities and targets. Moreover, the CRS-i members will continue to closely monitor the standardization activities in the main areas of interest, i.e., TV White Spaces, D2D and LSA in order to update this knowledge accordingly and to provide regular up-to-date feedback to the CRS cluster projects.

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