# 

# WInnComm-Europe 2014 Paper and Presentation Abstracts

# Tuesday, November 4

13:30 - 15:00

#### Technical Session 1A Waveform Software on SDR and SCA 1

**Novel Transformations of Extrinsic Information Applied to Innovative BICM-ID Receivers: Fundamentals and Limits**

Marc Adrat (Fraunhofer FKIE / KOM, Germany), Tobias Osten (Fraunhofer FKIE / KOM, Germany), Matthias Tschauner (Fraunhofer FKIE, Germany), Markus Antweiler (Fraunhofer FKIE, Germany) and Jan Lewandowsky (University of Federal Armed Forces Munich, Germany)

In this paper we propose a novel idea to increase the applicability of Bit Interleaved Coded Modulation with Iterative Decoding (BICM-ID) to legacy waveforms. One essential design parameter of BICM-ID receivers with respect to the error correcting capabilities is the symbol mapping of the digital modulation scheme. For instance, a so-called Semi-Set Partitioning (SSP) symbol mapping is well known to provide higher stepwise gains in robustness in every iteration than a Gray encoded symbol mapping. The novel approach is based on the idea to make in a first step in BICM-ID the deliberately false assumption that a well performing symbol mapping has been used at the transmitter, even though in reality a less powerful symbol mapping was applied. In a second step, the mismatch in both symbol mappings is compensated by a novel innovative transformation of extrinsic information. After having explained the novel idea in more detail, in this paper we will introduce the fundamentals of the required novel signal processing. In addition, we will present some first simulation results which demonstrate the best possible theoretically achievable performance gains.

**Low-Cost Fully-Software Waveforms for Tactical Communications**

Carmine Vitiello (University of Pisa, Italy), Giacomo Bacci (University of Pisa & Wireless Systems Engineering and Research (Wiser) Srl, Italy), Fulvio Arreghini (CSSN-ITE, Italy) and Marco Luise (University of Pisa & WISER srl, Italy)

The evolution of tactical radio has always been in contrast with money saving, both for the technical requirements of radio military standards and for the cost of new technological solutions. Until now hundreds of radio standards are born to satisfy the need to communicate in several ways and to operate in different scenarios and frequency ranges, and hundreds of hardware are made to handle this kind of communications. From this point of view, Software Defined Radios (SDRs) represent the present and the future of telecommunications and could be a promising solution in terms of costs and compactness. Their huge versatility, combined with new fast wideband components, allows several waveforms to be managed, exploiting the same platform hardware, covering large portion of frequency and reducing costs to buy and employ different hardware radios. Working on low-cost SDR platforms, some fully-software approaches have appeared in the last few years, thanks to the fact that all signal processing blocks can be run on General Purpose Processor (GPP), thus significantly reducing development costs and time. The paradigm has already been the winning choice for the diffusion of SDRs in the commercial field, also thanks to several open-source development tools. This methodology can also be applied in the military context, in which most research is orienting in developing waveforms jointly, based on a common Software Communication Architecture (SCA). Following this trend of research, this paper presents our recent results in which we focused on building several digital waveforms, such as STANAG 4285, STANAG 4539, MIL-STD-188-110A and MIL-STD-188-110B, to mention a few. In order to follow our low-cost philosophy, we implemented our codes on Ettus USRP B100 and USRP 1, one of the cheapest SDR platforms available on the SDR market, exploiting an open-source SCA-Compliant development tool, namely OSSIE in its last version, which guarantees the codes portability. This set of codes provides a suite of baseline waveforms useful to test the interoperability of different waveforms on several platforms, and to prove the potential of the fully-software approach on SCA environment. Thanks to several complexity-saving architectural choices, these waveforms require few resources in terms of occupied memory and CPU consumption, and they are able to be run also in a limited-resource equipment, always maintaining good communication performances.

**Portable platform-agnostic programming of wireless MAC protocols**

Giuseppe Bianchi (University of Rome "Tor Vergata", Italy)

Originally introduced as "just" cable replacements, wireless networks have today dramatically expanded their scope. Flexibility and run-time reconfigurability of wireless devices appears crucial to rapidly face mutating network and interference conditions. Services and deployment scenarios range from connected things to massively downloading human clients, from densely populated areas to largely diverse niche contexts (industrial automation, domotics, military, emergency, machine to machine, etc). And in many cases, the same wireless network is called to integrate a variety of services, types of terminals, and different delivery needs. On top of this, applications evolve continuously and in an unpredictable way, and wireless delivery performance (throughput, latency, etc) needs to adapt to the nature of the application or service being used. In contrast to the needs outlined above, today's deployed wireless technologies are inflexible. Commercial devices support one-size-fits-all standard protocols buried once for all inside the NIC implementation, and expose very limited facilities (if any) for customizing and/or adapting the channel access mechanisms to the possibly very specific and personalized context and service needs. As such, wireless networks suffer from an extremely slow pace of innovation, bound to the slow process of protocols' standardization and the therein emerging restrictions. This situation can be perhaps considered surprising, since the wireless community has been extensively working for as much as two decades on dynamic, software-based, reconfiguration of wireless devices, so as to more fully exploit the radio spectrum and to deliver data both faster and more reliably. This research effort has brought remarkable scientific and technological achievements (such as finding the right mix of programmable hardware to support high performance signal processing in radios), and has brought us to the point where performance, cost, and power consumption figures appear ready (or at least very close) to enable a viable real world transition from radios with behaviour fixed in hardware to radios with behaviour determined by software. However, we believe that the same wireless community has neglected some vital questions, such as how to describe the radio behaviour in a platform-independent manner. Indeed, very little attention has been paid so far to the identification of abstractions, formal models and languages, and programmatic interfaces devised to provide a platform-agnostic software-defined specification of wireless protocols and radio behaviour. In this paper/talk, we present concrete results, supported by implementation and experimental assessment, which provide a first research step towards this ambitious direction. Specifically, we present a wireless card architecture exposing a vendor-neutral programming interface which permits to formally describe wireless Medium Access Control protocols using an extended finite state machine (XFSM) abstraction. Byte-coded XFSMs can be dynamically deployed and executed on-demand over wireless cards, so as to reconfigure in real time the card's medium access control operation. Experiments and use cases involving the dynamic reconfiguration of ultra-cheap off-the-shelf commodity WLAN cards in less than one microsecond time, and showing the ability ot the proposed concept to support multiple, independent, MAC protocols from different tenants over a same wireless channel, show the flexibility and viability of the proposed concept.

#### Workshop 1B Spectrum Sharing and Spectrum Management 1

**Low Cost GSM/GSM-R Interference Detector and PLMNs discovery using Software Defined Radio Technologies**

Ottavio M. Picchi (WISER, Italy), Marco Della Maggiora (WISER srl, Italy), Irene Menicagli (University of Pisa, Italy) and Marco Luise (University of Pisa & WISER srl, Italy)

Interferences over GSM/GSM-R networks are suspected to increase in the near future, due to the expected growth of GSM-R network deployment and the potential growth of public cellular networks. The problem of interference over GSM-R spectrum has become a very sensitive theme since high speed train information is conveyed over the GSM-R radio signals. This clearly implies that an interference signal over the GSM-R band becomes a public safety criticality. In this paper we investigate a set of algorithms, which can be executed on an SDR-based sentinel to be deployed on the field. This sentinel is able to detect interference signals on the GSM/GSM-R bands as well as discover the PLMNs transmitting on the band under analysis.

**Spectrum Shared Wireless Sensor Networks based on Radio Environment Database**

Shunsuke Takagi (The University of Electro-Communications, Japan), Shunta Sakai (The University of Electro-Communications, Japan), Koya Sato (The University of Electro-Communications, Japan) and Takeo Fujii (The University of Electro-Communications, Japan)

In this paper, we propose a spectrum shared Wireless Sensor Networks (WSNs) that are able to coexist with Wireless Local Area Networks (WLANs) by avoiding interference to WLANs devices according to the radio environment database storing network and communication topology of primary systems. In this idea, WSNs gather information of not only physical layer information but also MAC layer information of spectrum shared WLANs. The gathered information is uploaded to Radio Environment Database located on the Internet. The database is connected with a spectrum manager and the gathered information from multiple sensor nodes are categorized for understanding the topology of APs and nodes of the spectrum shared WLANs. The spectrum manager evaluates the topology and received power of WLAN signals at each sensor node by using the registered information at the database. In this paper, we introduce the algorithm for establishing the measurement based MAC layer cooperated radio environment database for WSNs on ISM band.

15:30 - 18:00

#### Technical Session 2A Waveform Software on SDR and SCA 2

**DISIMAN: A Distributed SImulator for MANet in Software Defined Radio technology**

Maurizio Colizza (University of L'Aquila, DEWS, Italy), Fortunato Santucci (University of l'Aquila, Italy) and Marco Faccio (University of L'Aquila, Italy)

Simulation experiments are widely used in the domain of the Mobile Ad hoc Networks (MANETs) to evaluate the results of the design activities. These experiments must model the network topology, network traffic, routing and other network protocols, node mobility, physical layer issues, including the radio frequency channel, terrain, and antenna properties, and, perhaps, energy and battery characteristics. Accurate models are needed in order to realize high fidelity simulations; also, different models must be used at the same time to realize realistic scenarios. There are many resources involved in the computation of all models and protocols used in a MANET. Moreover, if the nodes in a MANET are in Software Defined Radio Technology (SDR) there is a further element of complexity. This is because both the protocols and the resources channel may change during the time of work. Consequently, each simulation provides issues of Big Data and computation scalability. A Cloud approach is useful to overcome these issues. In this paper we propose an information system for the management of simulations and emulations of MANET networks. The information system is named DIstributed SImulator for MANet. DISIMAN provides scalability both for data storage resources and for the computation resources. To do this, the paper show how to integrate cloud solutions (e.g. akka, HBASE) by using the Tissue Methodology. Also, the paper shows a scalable embedded architecture for SDR devices.

**Conclusions of the EDA Study on the Application of Multiple and Independent Levels of Security to SDR (AMIS)**

Alberto Quintana (Indra, Spain)

The concept of MILS ("Multiple and Independent Levels of Security") establishes the splitting and management of the information with different levels of classification in an isolated way within the same equipment. On the other hand, the SDR technologies can be applied both to single-channel and multi-channel radios. Each waveform executed in a multi-channel radio may be used to transmit and receive user data with different levels of classification (SECRET, CONFIDENTIAL, RESTRICTED...). Additionally a single waveform may require dealing with user traffic with different levels of classification. The proposed presentation provides an overview on the high level conclusions of the EDA study on the application of MILS to SDR systems.

**Security Study on SDR Tactical Terminals**

Rafael Aguado (Global SDR, Spain)

As the Software Defined Radio (SDR) terminals evolve the security of these terminals get more and more compromised. The network capabilities and the new features introduced in such terminals (as SNMP) shorten the differences between the traditional web security and SDR-based networks security. The typical command and control headquarter has evolve during the last few years, were the hardware based terminals has been replaced for SDR terminals working together seamlessly in different network configurations supporting voice and data and operating both in broadcast and point-to-point mode. This joint scenario forces to introduce new security requirements as the increased connectivity drive the tactical communications to be closer to cloud connection domain. Having said that, the paper proposes a change in the security paradigm study. Many systems fail because designers protect the wrong things or even worse, the right things in a wrong way. The survey will not only study the architectural paradigms, but also will explore the main data paths established among the different subsystems, highlighting where the risks and threats are in a practical approach, identifying what has to be protected and the best ways to do so. Lastly the paper will investigate how the JTRS SCA framework, focusing in its last version, influences the security mechanisms that need to be established in order to fulfill the requirements from the standard.

#### Workshop 2B Spectrum Sharing and Spectrum Management 2

**Field Tests of Database-assisted V2V Communications over TV White Space**

Onur Altintas (Toyota InfoTechnology Center, Japan), Koichi Seki (Toyota InfoTechnology Center, Japan), Kohsuke Nakagawa (Toyota InfoTechnology Center, Japan), Toshihiko Watanabe (Toyota InfoTechnology Center, Japan), Haris Kremo (Toyota InfoTechnology Center, Japan) and Hideaki Tanaka (TOYOTA InfoTechnology Center, Japan)

Using a centrally authorized geolocation database is recently being ruled as the preferred method of primary user protection in certain markets. The secondary user must be location aware, and must periodically access the database querying the information regarding available white space. In centralized network topologies, base stations can query the database on behalf of individual users. In an ad-hoc vehicle-to-vehicle communications setting, additional wireless connectivity to query the database would be necessary in each vehicle. On the other hand, depending on the market, the regulators require that a mobile node perform a database query whenever it moves for more than 100 meters. If this rule is adopted for vehicular networks, a vehicle traveling at 100 km/h would create one database query every 3.6 seconds. A better way of accomplishing this could be to have one vehicle act as a proxy to obtain information from the database and distribute it among its peers, not only for the current location but also for "future" locations, by taking hints from the vehicles' velocity vectors. In this paper, we first describe the general architecture which makes dual use of a geolocation database and spectrum sensing. In this architecture, whenever a database query result is available, that information is prioritized over sensing results and when the database access is disrupted, vehicles rely on the spectrum sensing results. After describing the general concepts, we present the middleware-centric implementation and field test results of a multi-hop vehicle-to-vehicle communications over the licensed TV-band. We present results regarding multi-hop throughput, delay, jitter, channel switching and database access latencies.

**Transmission decision algorithm for updating sensing information**

Mai Ohta (Fukuoka University, Japan)

This paper proposes the decision method for transmitting a sensing information that depends on a surrounding environment. The sensing node decides autonomously a transmission timing based on detection result of a change of the measured environment. Then the received fusion center can update a stored statistical information. However there is a relationship between the transmission interval and the detection probability of the change of the environment, because the transmission interval and the measurement period is the same. By using this relationship, the sensing node can avoid using the wireless resources wastefully. This paper clarifies the relationship and evaluates the proposed method by using simulation.

**Distributed spectrum sensing using low cost hardware**

Stefan Grönroos (Åbo Akademi University, Finland), Kristian Nybom (Åbo Akademi University, Finland), Jerker Björkqvist (Åbo Akademi University, Finland), Juhani Hallio (Turku University of Applied Sciences, Finland), Jani Auranen (Turku University of Applied Sciences, Finland) and Reijo Ekman (Turku University of Applied Sciences, Finland)

A distributed spectrum sensing network is prototyped using off the shelf hardware consisting of Raspberry Pi minicomputers and DVB-T receivers with software defined radio capabilities. Using the prototype network, coordinated, distributed wideband spectrum sensing is performed in a geographical area. The spectrum sensing data from the nodes is collected in a database. Well established low-complexity algorithms for distributed spectrum sensing are applied, and the results are compared against a professional spectrum sensing system. We show that with this simple low-cost setup, the decisions made on the availability of spectrum using the distributed sensing data correspond well with the decisions made on the reference data.

# Wednesday, November 5

10:30 - 12:00

#### Workshop 3B Spectrum Sharing and Spectrum Management 3

**Spectrum Sharing and Critical Infrastructure Protection**

Daniel Devasirvatham (Idaho National Laboratory, USA)

Spectrum sharing has become an area of great interest in future communications. It has been accelerated in the US by the President's directive to the US Government to share portions of its spectrum with the commercial world. The foundation for this was laid in the US by the PCAST (President's Council of Advisors on Science and Technology) report. Similar efforts are being undertaken in Europe as well. An important understanding that has been developing recently is the idea that wireless is now an integral part of Critical Infrastructure (CI) and therefore, Critical Infrastructure Protection (CIP) by necessity requires the protection of vulnerabilities in Wireless Communications as well, especially those that can be used to disable key sectors in CI, such as nuclear, oil and gas power plants, refineries, Bridges, and dams. SCADA networks and more advanced forms of M2M communications are now integral to the operation and safety of CI. Spectrum sharing throws another twist into the mix. When some major incident happens, and hence, traffic volume goes up, congestion and delay could have deleterious consequences on the safe and stable operation or at least the optimum operation of the CI. In cases where there is significant damage to some element of CI, rerouting of functions (or power in the case of the smart grid) requires reliable and well understood traffic paths to execute protection and disconnection strategies. Spectrum sharing adds several unknowns and also vulnerabilities to this scenario. It could also provide additional ways in which someone wishing to do harm could magnify the effects of the incident by additional cyber-attacks via the links that provide the spectrum sharing. The paper examines some of these scenarios and discusses opportunities from and challenges to this approach. It should help heighten awareness of potential real world consequences which need to be taken into account as these systems are designed and deployed. Plans for implementing the concepts in a safe test bed are also discussed.

**Adaptive parameter control for cooperative spectrum sensing for wireless vehicular networks based on measurement-based spectrum database**

Kohsuke Nakagawa (The University of Electro-Communications, Japan) and Takeo Fujii (The University of Electro-Communications, Japan)

In spectrum sharing, Radio environment reorganization methods are important technology to avoid interference to Primary Users (PU) from Secondary Users (SU). Radio environment reorganization methods such as FCC defined spectrum database and spectrum sensing have been studied extensively. Recently, Wireless Vehicular Network (WVN) with CR has been proposed as a promising approach to the growing demand of the spectrum for new applications requiring high speed and high capacity. However, the existing radio environment reorganization methods remain a significant challenge in WVN. Thus, this paper proposes a novel adaptive parameter control cooperative spectrum sensing method based on measurement-based database proposed by us. In this adaptive cooperative sensing, firstly, SU sends GPS information to request the average received power stored in database at the point. Its information enables SU to estimate sensing performance by using theoretical formula of detection probability considering surrounding situation like fading channel, mobility and available cooperation vehicles. Based on the estimated sensing performance, SU determines parameters to perform cooperative sensing. In this way, the proposed method ensures stable sensing performance and reduces sensing cost because SU is able to sense adaptively on various environments. From simulation results, the proposed method shows more stable detection probability and lower false alarm rate at various environments with suppressed sensing costs than the current radio environment reorganization methods.

**Dynamic TV White Spaces database: practical implementation and trial results**

Paulo Marques (Instituto de Telecomunicações, Portugal)

TV White Space (TVWS) frequencies are becoming a real world test laboratory of dynamic spectrum sharing. A challenging aspect of TVWS use in Europe is that TV spectrum is not only occupied by fixed TV broadcasting signals. In addition to the TV broadcasts the spectrum is used by licensed Programme Making Special Event (PMSE) devices, e.g., wireless microphones. TV White Space cognitive device operation may be permitted if (and only if) it does not interfere with incumbent services such as digital TV and PMSEs. White Space devices should either sense the presence of incumbent systems or make use of a geo-location database to determine which spectrum is unused in the vicinity. Current regulation in the US and UK are supporting the solo use of the geolocation database. However it is increasingly recognized that a solution based on exploiting spectral sensing coupled with geolocation databases allows a more effective use of TVWS. In particular, a geolocation database assisted by a low-cost and densely deployed spectrum monitoring infrastructure is a promising approach to protect dynamic incumbent systems, such as wireless microphones that are not registered in the database. Until now, neither Europe nor the US have conducted any white space field trials that adopt a hybrid approach. An important aspect is to evaluate the benefits of this hybrid solution in the coexistence between incumbent and white space systems operating in the TV bands. This presentation will show for the first time the results of a trial that combines geo-location database access with a spectrum-monitoring network available in the Logatec city (Slovenia). This work was carried out under the EU research project FP7 CREW (www.crew-project.eu). In this trial we assume that PMSEs are not registered in the database (a common scenario in many EU countries) and therefore its protection completely relies on sensing. Once the PMSEs transmitter are detected by a distributed sensing algorithm, the geo-location database is informed and automatically removes from the white space maps an exclusion region around the PMSEs location. In this exclusion area, transmission of cognitive users of the TV spectrum is temporarily not allowed. This trial allowed the experimental investigation of several research issues such as the minimum density of the sensor network to get reliable sensing information and the methodology to compute the minimum exclusion area to protect PMSEs. Another interesting result is the impact of WSD's location uncertainty on the incumbent and the secondary systems coexistence. This is realized by adding a location error parameter to the actual WSD's location. In this presentation we will explain the technical specifications of the sensing network, the approach to populate the geolocation database and the methodology to combine sensing with TV white space maps stored in the database. The TV white space maps for Slovenia were computed according to the algorithm and procedure describe in ECC (Electronic Communications Committee) Report 186, with a 200 m resolution grid. For a selected area, the white spaces availability data can be exportable to a log file using the common format and used in subsequent experiments. The sensor network used in the trial is operated by the Jozef Stefan Institute (JSI) from Slovenia and is available as part of the European FP7 CREW project ( www.crew-project.eu/vsn ). The core of the JSI testbed consists of a sensor network containing approximately 50 low cost nodes mounted on public lighting infrastructure in the Logatec city. The sensor nodes on light poles are equipped with different spectrum sensing and signal generation capabilities, including the VHF/UHF frequency bands. Each node hosts a GPS module providing internal geolocation and precise reference timing capability. The nodes have IP connectivity and can be remotely reprogrammed according to the needs of the investigated use case. The communication with the geo-location database is implemented by a draft version of the IETF PAWS (Protocol to Access White Spaces). The main objective of this protocol is to allow a WSD to request spectrum access to the geolocation database, and retrieve a list of available channel to operate as a secondary user. The implementation includes a graphical user interface (GUI) visualising the message flow between the database and the WSD. A demo showing PAWS operation with the TVWS database will be shown during the presentation (online available here: www.cmsf.eu/projects/crew-tv/paws.php ). The trial was carry out in the Logatec city (Slovenia) to assess the benefits of combining a white spaces database with a distributed sensing network in the coexistence between WSDs and incumbent systems in TV bands. An important result is the ability of the geolocation database to automatically create protection areas around detected wireless microphones devices using real-time information from the sensing network. The presentation will be split in two parts. The first part will present the experiment set up and the main results from the trial, in the second part we will provide a live demonstration of the geo-location database and the sensor network that are remotely accessed from a laptop, using a web GUI: www.cmsf.eu/projects/crew-tv/white\_spaces.php In summary we will highlight the benefits and showcase the technical feasibility of dynamic spectrum databases, i.e., the combination of a pre-computed white spaces maps with real-time information from a distributed sensing network. At regulatory level, the research results from this trial will help administrations to recognize the value of spectrum monitoring as part of the progressive approach to managing spectrum more efficiently.

12:00-14:00

**Posters**

**A SDR Implementation of CoMP Transmission on GPP Platform**

Bobo Cheng (Tsinghua University, P.R. China), Xiang Mi (Tsinghua University, P.R. China), Zhan Xu (Beijing Information Science and Technology University, P.R. China), Limin Xiao (Tsinghua University, P.R. China), Xibin Xu (Tsinghua University, P.R. China) and Ming Zhao (Tsinghua University, P.R. China)

CoMP (Coordinated Multiple Points) has been verified to be an effective way to improve the throughput of cell edge users in LTE-Advanced. Due to high computational and intensive data exchange, Many CoMP systems are implemented on hardware platforms such as DSP, FPGA, etc. In this paper, We implemented a real-time downlink CoMP joint processing on GPP(General Purpose Processor) platform based on TD-LTE R8/R9 protocols. We adopted socket connection as data exchange interface between soft CoMP base stations and optimized data exchange categories to cut unnecessary data communication. To enable real-time processing, we accelerate our programs with some parallel processing techniques such as multi-threads,SIMD,etc. The test results show that the running time of our system can satisfy the requirement of real-time CoMP processing.

**Energy Optimization Using MSK Modulation Technique In Wireless Sensor Networks**

Rajoua Anane (Laboratory of Acoustics at University of Maine, LAUM & Innovation of Communication, Innov'com, Sup'com, France)

As wireless sensor networks use battery-operated nodes, energy efficiency is a very important metric. In this context, optimally selected modulation is an extremely vital technique in wireless sensor networks. This paper presents a comparative analysis of different modulation techniques in order to find the best modulation strategy to minimize the total energy consumption. The digital modulation schemes that we have studied and compared on the basis of total energy consumption are M-ary Quadrature amplitude modulation (MQAM), M-ary Frequency-shift keying (MFSK), M-ary Phase-shift keying (MPSK) and minimum-shift keying (MSK). Simulation results are presented to illustrate the performance of MSK modulation technique compared to its counterparts in Additive White Gaussian Noise (AWGN) channel conditions. We confirm, through mathematical formulation and simulation that energy consumption per information bit can be improved by optimizing constellation size and transmission time at a specific distance.

14:00 - 15:30

#### Technical Session 4B Context Aware Cognitive Radio

**Dynamic TV White Spaces database: practical implementation and trial results**

Paulo Marques (Instituto de Telecomunicações, Portugal)

TV White Space (TVWS) frequencies are becoming a real world test laboratory of dynamic spectrum sharing. A challenging aspect of TVWS use in Europe is that TV spectrum is not only occupied by fixed TV broadcasting signals. In addition to the TV broadcasts the spectrum is used by licensed Programme Making Special Event (PMSE) devices, e.g., wireless microphones. TV White Space cognitive device operation may be permitted if (and only if) it does not interfere with incumbent services such as digital TV and PMSEs. White Space devices should either sense the presence of incumbent systems or make use of a geo-location database to determine which spectrum is unused in the vicinity. Current regulation in the US and UK are supporting the solo use of the geolocation database. However it is increasingly recognized that a solution based on exploiting spectral sensing coupled with geolocation databases allows a more effective use of TVWS. In particular, a geolocation database assisted by a low-cost and densely deployed spectrum monitoring infrastructure is a promising approach to protect dynamic incumbent systems, such as wireless microphones that are not registered in the database. Until now, neither Europe nor the US have conducted any white space field trials that adopt a hybrid approach. An important aspect is to evaluate the benefits of this hybrid solution in the coexistence between incumbent and white space systems operating in the TV bands. This presentation will show for the first time the results of a trial that combines geo-location database access with a spectrum-monitoring network available in the Logatec city (Slovenia). This work was carried out under the EU research project FP7 CREW (www.crew-project.eu). In this trial we assume that PMSEs are not registered in the database (a common scenario in many EU countries) and therefore its protection completely relies on sensing. Once the PMSEs transmitter are detected by a distributed sensing algorithm, the geo-location database is informed and automatically removes from the white space maps an exclusion region around the PMSEs location. In this exclusion area, transmission of cognitive users of the TV spectrum is temporarily not allowed. This trial allowed the experimental investigation of several research issues such as the minimum density of the sensor network to get reliable sensing information and the methodology to compute the minimum exclusion area to protect PMSEs. Another interesting result is the impact of WSD's location uncertainty on the incumbent and the secondary systems coexistence. This is realized by adding a location error parameter to the actual WSD's location. In this presentation we will explain the technical specifications of the sensing network, the approach to populate the geolocation database and the methodology to combine sensing with TV white space maps stored in the database. The TV white space maps for Slovenia were computed according to the algorithm and procedure describe in ECC (Electronic Communications Committee) Report 186, with a 200 m resolution grid. For a selected area, the white spaces availability data can be exportable to a log file using the common format and used in subsequent experiments. The sensor network used in the trial is operated by the Jozef Stefan Institute (JSI) from Slovenia and is available as part of the European FP7 CREW project ( www.crew-project.eu/vsn ). The core of the JSI testbed consists of a sensor network containing approximately 50 low cost nodes mounted on public lighting infrastructure in the Logatec city. The sensor nodes on light poles are equipped with different spectrum sensing and signal generation capabilities, including the VHF/UHF frequency bands. Each node hosts a GPS module providing internal geolocation and precise reference timing capability. The nodes have IP connectivity and can be remotely reprogrammed according to the needs of the investigated use case. The communication with the geo-location database is implemented by a draft version of the IETF PAWS (Protocol to Access White Spaces). The main objective of this protocol is to allow a WSD to request spectrum access to the geolocation database, and retrieve a list of available channel to operate as a secondary user. The implementation includes a graphical user interface (GUI) visualising the message flow between the database and the WSD. A demo showing PAWS operation with the TVWS database will be shown during the presentation (online available here: www.cmsf.eu/projects/crew-tv/paws.php ). The trial was carry out in the Logatec city (Slovenia) to assess the benefits of combining a white spaces database with a distributed sensing network in the coexistence between WSDs and incumbent systems in TV bands. An important result is the ability of the geolocation database to automatically create protection areas around detected wireless microphones devices using real-time information from the sensing network. The presentation will be split in two parts. The first part will present the experiment set up and the main results from the trial, in the second part we will provide a live demonstration of the geo-location database and the sensor network that are remotely accessed from a laptop, using a web GUI: www.cmsf.eu/projects/crew-tv/white\_spaces.php In summary we will highlight the benefits and showcase the technical feasibility of dynamic spectrum databases, i.e., the combination of a pre-computed white spaces maps with real-time information from a distributed sensing network. At regulatory level, the research results from this trial will help administrations to recognize the value of spectrum monitoring as part of the progressive approach to managing spectrum more efficiently.

**Experimental performance comparison and analysis for various MAB problems under cognitive radio framework**

Navikkumar Modi (SUPELEC/IETR, France), Christophe Moy (SUPELEC/IETR, France) and Philippe Mary (INSA Rennes, IETR UMR CNRS, France)

This presentation gives a brief overview and experimental performance comparison of different types of the online sequential decision making Multiarmed bandit (MAB) problem for the cognitive radio opportunistic spectrum access. In this work, we consider online learning problem of classical, rested and restless MAB for single user/arm and furthermore, it will be extended for the multiple users/arms. A classical MAB problem assumes independent and identically distributed (i.i.d) rewards, while rested and restless formulation of the MAB assumes Markovian rewards. The fundamental objective of the MAB formulation is to maximize the total rewards obtained by playing the best optimal arm. The classical difficulty of the MAB is a fundamental trade-off between exploration and exploitation, which requires an efficient policy design to achieve optimum performance. The short introduction and performance analysis of the various policies (UCB1, UCB Tuned, KL-UCB, etc.) are done by analyzing regret, which is defined as a reward loss compare to optimal performance. For almost all the algorithms, a detailed theoretical analysis of the regret bound is available, while it's important to analyze the experimental performance of the different policies on various MAB formulations. The experimental performance of different MAB algorithms could be easily assessed case by case of specific problems, but it would be interesting to present a more convincing comparison of their actual experimental performance. The main objective of the presentation is to provide an extensive experimental analysis of existing MAB algorithms along different dimensions such as, expected regret, optimal arm selection, and computational complexity. Furthermore, some experimental measurements under dynamic spectrum access framework are carried out for the validation of the theoretical results. References: 1. Jouini, W.; Ernst, D.; Moy, C.; Palicot, Jacques, "Upper Confidence Bound Based Decision Making Strategies and Dynamic Spectrum Access," Communications (ICC), 2010 IEEE International Conference on , vol., no., pp.1,5, 23-27 May 2010 2. Tekin, C.; Mingyan Liu, "Online Learning of Rested and Restless Bandits," Information Theory, IEEE Transactions on , vol.58, no.8, pp.5588,5611, Aug. 2012 3. Haoyang Liu; Keqin Liu; Qing Zhao, "Learning in a Changing World: Restless Multiarmed Bandit With Unknown Dynamics," Information Theory, IEEE Transactions on , vol.59, no.3, pp.1902,1916, March 2013

**IPA Volume 3: Cognitive Radio Context, WISDM, and Big RF**

James Neel (Cognitive Radio Technologies, LLC, USA), Peter G. Cook (Hypres, Inc., USA), Ihsan A Akbar (Harris Corporation, USA), Neal Mellen (6. Wireless Spectrum Management, LLC, USA), Shaswar Baban (King's College London & IEEE, United Kingdom), Charles Sheehe (NASA, USA), Robert Schutz (Artisan Wireless, USA) and Daniel Devasirvatham (Idaho National Laboratory, USA)

This presentation will provide an overview of key results produced during the Cognitive Radio Work Group's (CRWG) Information Process Architecture (IPA) Volume 3 project. No separate paper will be prepared for this presentation as parties interested in information beyond the content of the presentation should refer to the accompanying Wireless Innovation Forum report that will be in ballot coincident with the conference. The IPA v3 project principal contributions were in the following three areas: • Context aware cognitive radio • WISDM (Wireless Information System Descriptive Model) • Big RF For context aware cognitive radio, the CRWG developed use cases where additional context would aid in wireless network performance, surveyed languages and existing tools for implementing context-aware systems, implemented a test design using one of these tools (Context Toolkit), and made recommendations for designing and implementing context aware cognitive radio systems. The CRWG's work on context aware cognitive radio and WISDM are currently being built upon by the Wireless Innovation Forum Public Safety Special Interest Group (PSSIG) in a project that is defining how the use of contextual information can improve the performance of public safety networks in varying operational scenarios. WISDM is a newly developed model for describing and analyzing intelligent systems, with a particular emphasis on modeling and supporting the design of context-aware cognitive radio systems. The application of WISDM allowed us to identify gaps and insertion points in our proposed Big RF architecture and led to the proposal of a new position in public safety networks - the Information Leader (Info-L). Further applications of WISDM allowed us to show that all surveyed existing models of intelligent systems could be represented by a subset of WISDM components. Big RF is the application of Big Data tools and concepts to RF domain problems. The rapid distillation of actionable information from countless sensors and radios is critical to providing contextual awareness to cognitive radio systems. Network accessible Big Data tools, storage, and techniques will be necessary to achieve this vision, which generalizes to address a wide variety of spectrum management and coexistence of more advanced shared spectrum applications, such as enabling 3.5 GHz operation, hospital room management, smart grid applications, and large scale military network management. A key difference explored in the report between conventional Big Data designs and Big RF designs is that cognitive radios, spectrum databases, and spectrum management systems will be both data generators and analysis consumers for most Big RF systems.

16:00 - 17:00

## Workshop 5A Tactical Radio 3

**An approach to Test and Evaluation of Military SDR Platforms and Waveforms: the LANCERS lab**

Fulvio Arreghini (CSSN-ITE, Italy), Carmine Vitiello (University of Pisa, Italy), Marco Luise (University of Pisa & WISER srl, Italy), Andrea Manco (CSSN-ITE, Italy), Giacomo Bacci (University of Pisa & Wireless Systems Engineering and Research (Wiser) Srl, Italy) and Matteo Falzarano (Italian Navy, Italy)

SDR is today one of the most appealing technology both for military and commercial market. Among the main benefits of SDR there are flexibility and portability, given by the possibility to develop Waveform (WF) independently from the platforms where they will be hosted. this makes the signal processing completely decoupled from the RF hardware. For the military community, SDR, thanks to its intrinsic flexibility, is regarded as a key enabler of interoperable communications within different scenarios: a unique SDR platforms could be employed with different waveforms for national and coalitional scenarios or even for interoperability with NGO. In the USA, The JTNC Software Communications Architecture (SCA) provided a unique reference for SDR. Based on this reference, guidelines for manufacturers and developers, as well as test tools were developed. Even if JTNC SCA is regarded as a de facto standard for the mayor European SDR programs, Europe panorama is more complex than USA one: first, the JTNC standards and procedures are not suited to be used on a European basis. In addition, several programs dealing with SDR exist, based on national or multinational initiatives and a common standard is still missing. Each program has different requirements and different policies related to security and IPRs. This rises some issues regarding how evaluation and certification process should be carried out: a number of different models for a European standardization and certifications have been proposed, identifying candidates standardization and/or certification bodies. In almost all these models, a network of test labs, located in different nations and accredited by a competent body, is foreseen as the most likely solution. These labs should have the capability and credibility to perform an evaluation process and should have mutual recognition with each other. Italian MoD is involved in SDR since 2002 and is part of the mayor multinational programs, such as ESSOR and COALWNW. In addition, as an outcome of the national SDR program, a complete family of SDR products is under development and some products are already available. In 2011 the Italian Ministry of Defense (MoD) decided to develop a national test and evaluation capability of future SDR products, and identified the Centro di Supporto e Sperimentazione Navale (CSSN) - Istituto per l'Elettronica e le Telecomunicazioni (ITE), based in Livorno, Italy, as the main technical center for its implementation, supported by a funding program running until 2015. In this paper we present the approach of the Italian Ministry of Defense (MoD) to the test and evaluation (T&E) process of military SDR. After describing key principles and choices made by Italy regarding military SDR, we will give a focus on the role of Italy in the International SDR Community. We will then describe the process of development of a national T&E capability for military SDR and the activities carried out at CSSN ITE Livorno to start the T&E Lab, named LANCERS. Finally the current situations of the activities of the LANCERS lab and future work will be presented.

**Field research and evolution to Cognitive Radio**

Enrico Del Re (University of Florence, Italy) and Luca Simone Ronga (CNIT, Italy)

Cognitive Radio has been considered as most promising innovation since its initial concept and definition at the beginning of this millennium. Empowered by unseen advances in several technology fields like Software Defined Radios, available computing power, fast signal acquisition and processing, low energy consumption and programmable gate arrays, as the key enablers of cognitive paradigm, its development followed a long experimental research path with pioneering projects in several areas of digital communications. Among them a fully programmable prototype modem for space communications, multi-standard radio architectures based on general purpose processors and advanced secure wireless waveforms implemented on programmable gate arrays. Since the initial concepts of Cognitive Radio a growing set of research themes started to appear, ranging from software architectures supporting re-configurability and cognition like GNU Radio, Ossie and SCA, to evolved networking concept like Cloud RAN and Software Defined Networking. We still assist to a continuous evolution of the Cognitive Radio paradigm, but its mass adoption is far from being realized. Some considerations will be provided.

#### Workshop 5B Software Defined Radio 1

**Experimental Indoor Deployment of CloudRAN GSM Emergency Services**

Luca Simone Ronga (CNIT, Italy) and Enrico Del Re (University of Florence, Italy)

The increasing availability of computing power enables new paradigms of radio communication services. The centralized baseband processing of cellular networks reveals some interesting features such as an high degree of re-configurability, high efficiency in terms of processing power and consumed energy, fast deployment especially useful in the case of unplanned emergency networks. This paper reports an indoor multi-cell experimental deployment of GSM voice and message communications services with low-cost SDR technology. The experimental setup is characterized by a centralized processing of baseband signals, delivered with optical fiber links to RF heads. Quality of experience and resources usage analysis has been performed and reported as an evaluation of the feasibility of this approach with low-cost HW and devices.

**Evaluation and Analysis of Influence from Other Radio Systems in Wideband Non-Contiguous OFDM Receiber**

Keiji Takakusaki (Advanced Telecommunications Research Institute International, Japan), Kazuhiro Kosaka (Advanced Telecommunications Research Institute International, Japan), Issei Kanno (ATR : Advanced Telecommunication Research Institute International, Japan), Akio Hasegawa (ATR Adaptive Communications Research Lab., Japan) and Hiroyuki Shinbo (ATR, Japan)

We are studying the Wideband Non-Contiguous OFDM (WNC-OFDM) to utilize an unused frequency band. The WNC-OFDM can realize a high-speed communication by gathering OFDM sub-carriers which are dispersively located unused frequency bands across extremely wide target bands. Since a WNC-OFDM transmission uses multiple dispersed frequency bands at the same time, its receiver needs to receive wideband signal including all disperesed bands. In this case, since the receiver receives not only the desired WNC-OFDM signals but also the undesired signals of other systems simultaneously, WNC-OFDM signals are affected by interference due to other radio systems signal. It is important to comprehend the influence from other radio systems and tolerance for them in order to design and tune the WNC-OFDM transceiver. In our previous research[1], the influences from other radio systems were evaluated through the experimentation with developed equipment and the computer simulations. The results showed bit error ratio performances were quite difference from the performance in Gaussian noise environment. In this paper, we conducted theoretical analysis and confirm validity of the interference characters observed in the previous evaluation.

**Enabling LTE and Next Generation 5G Wireless Research with Software Defined Radio**   
  
Erik Luther (Ettus Research, USA)

Open source efforts, such EURECOM's OpenAirInterface, are providing a 3GPP compliant LTE software stack for use with off-the-shelf software defined radio (SDR). Such innovations are accelerating the adoption of SDR for prototyping current generation and next generation 5G communication systems. In this session we explore new developments in software and hardware that are making SDR technologies more accessible for research and deployment applications with specific examples that include 3GPP compliant LTE with OpenAirInterface, Massive MIMO testbed development, and mmWave research with the aim of meeting growing demands for latency, capacity, and reliability in future 5G systems.

# Thursday, November 6

08:30 - 10:00

#### Workshop 6A Tactical Radio 4

**Challenges of SDR waveforms portability for tactical communications, an industry perspective**

David Renaudeau (Thales, France)

Portability of waveforms is a key concern of some SDR programs, for example the national SDR programs including national WF development to ensure interoperability between forces, or the coalition waveform programs aiming to develop waveform to be used by different nations into operations. This presentation will provide an industrial perspective of the challenges of the portability of waveforms for different use cases, enabling Multi-Waveforms, Multi-Platforms, Multi-Suppliers business models.

**Current status of SVFuA and way ahead from an industry perspective**

Boyd Buchin (Rohde & Schwarz, Germany) and Ruediger Leschhorn (Rohde & Schwarz, Germany)

With the project "Streitkräftegemeinsame, Verbundfähige Funkgeräte-Ausstattung" (SVFuA, radio system for joint and combined operations) the Bundeswehr set out to modernize its tactical communication system for mobile operations. With the completion of the radio sets for 2- and 3-channel-communication - together with the reference waveform FM3TR and a wideband networking waveform from a previous study - the basis for the integration of SVFuA into its surrounding system has been set. The presentation will highlight the key requirements that were decisive for the design of SVFuA and the chosen approach to portability, to enable the platform to support multiple waveforms, multiple levels of security to enable national and multinational communication and a smooth migration from legacy systems to current and future mission networks.

#### Workshop 6B Software Defined Radio 2

**INVITED PRESENTATION: FPGA-based Broadband Processing in Space**

Robért Glein (Fraunhofer Institute for Integrated Circuits, Germany)

The Fraunhofer On-Board Processor (FOBP) is a dynamically reconfigurable On-Board Processor (OBP) platform consisting of two signal processing paths. In order to perform reliable high-speed processing, we introduce this SDR platform based on space-grade analog devices, ADCs, reconfigurable FPGAs (Virtex-5QV) and DACs. We address a wide range of center frequencies, bandwidths and communication applications due to a variable low noise sampling clock and undersampling. In the Heinrich-Hertz communication satellite application we process a 450 MHz transponder at an intermediate frequency in the L-band. In a case study we demonstrate an implementation of a Digital Down Converter (DDC) processing a 306 Mbit/s broadband signal, modulated with Quadrature Phase-Shift Keying (QPSK). Furthermore we discuss a fail-safe reconfiguration for the FPGAs and Single Event Effects (SEEs) for the harsh Geostationary Earth Orbit (GEO) radiation environment.

**INVITED PRESENTATION: Innovative implementation of transmitter and receiver architecture for tactical SDR radio**

Antonio DiRocco (Selex ES, Italy)

Transition from conventional radio front-end to software-defined-radio involves a number of issues mainly due to the requirement of the RF chain to be independent by the RF chain design in term of protection circuits, intermediate frequencies, radio frequencies, adopted communication scheme and employed modulation. Besides, a set of industrially compulsory requirements as optimized power consumption, reduced size and costs makes the overall picture very challenging and design-proof. This paper encompasses a certain number of solutions that may be included into the design of the RF front-end of SDR tactical radios. Circuital solutions are pertaining with: • a low IF receiver that simultaneously performs a low-cost and performant image and interference rejection; • a transmitter architecture including a Polar Modulator for high-efficiency power amplification • a RF path protection to avoid breakages due to overvoltages

**Enhancing GNURadio Processing Blocks Migration from Software to Hardware**

Roberto de Matos (Federal Institute of Santa Catarina, Brazil) and Cleiber da Silva (GH3 Tecnologia, Brazil)

Software Defined Radio (SDR) provides a generic physical layer that along with a software part is able to reproduce several communication standards. SDR has emerged as an alternative approach to provide adaptable wireless communication capacity, however, a typical drawback is the high coupling between the software and the hardware layers and the platforms heterogeneity, which makes hard to migrate the software part to the hardware to achieve better performance. To overcome this problem, this paper presents a hardware platform entire developed at Federal Institute of Santa Catarina, which runs an embedded GNU Radio version and allows to migrate any part of flow graph to a programmable logic IP. The solution applies a coarse-grained reconfigurable computing approach that uses a Network-on-Chip (NoC) to enhance the internal communication infrastructure and hardware accelerators to speed up DSP-related algorithms. A high speed communication interface with the general purpose processor running GNU Radio allows a block located anywhere in the flow graph to be placed on the FPGA. It was possible to achieve creating a new block in GNU Radio that sends samples to a hardware block and get the post-processing samples back to the flow graph. To prove our concept we implemented a test bed that consists of intercepting PTP Walkie-talkie communication. It basically requires a spectrum sensing algorithm and an FM demodulator. The results from such experiments are presented and discussed along the paper as well as the architecture impacts of free transit of processing blocks between hardware and software.

10:30 - 12:00

#### Workshop 7A Tactical Radio 5

**Managing SDR in the field - Trial/Experiment/Deployment**

Mario Sommaruga, Mauro Piccone (Selex ES. Italy)

**Model-Based Testing for SCA Conformance Testing**

Julien Botella (Smartesting, France), Eddie Jaffuel (eConsult, France), Bruno Legeard (Smartesting & FEMTO-ST - UFC, France) and Fabien Peureux (Institut FEMTO-ST & Smartesting Company, France)

The Software Communications Architecture (SCA) is a software architecture produced and maintained by the JTNC (Join Tactical Networking Center). Facing the multiplicity of the waveforms and the diversity of the platform architectures and form factors, the original aims of the SCA are to facilitate the waveform development in terms of portability and waveform deployments onto heterogeneous SDR platforms. In this paper, we present an approach using Model-Based Testing (MBT) to ensure the conformance of a software radio platform to SCA requirements. In this approach, an MBT model is developed on the basis of SCA specifications, and conformance tests and scripts are generated and then run on the targeted software radio platform. This approach has been developed within a National Research Project called OSeP, with results regarding modeling for automated test generation for SCA conformance testing. The techniques involved in this project focus on functional requirements and generate automated test scripts that are executed using a test execution environment in Java. Keywords: Software Communications Architecture (SCA), conformance testing, model-based testing, dynamic testing.

**CORASMA project: main results and achievements**

Christophe J. Le Martret (Thales Communications & Security & Signal Processing and Multimedia Dept., France)

CORASMA (Cognitive radio for dynamic Spectrum Management) is a 3 year duration EDA (European Defence Agency) program of category ad hoc B that ended in November 2013. The aim of the CORASMA project was to study the application of the cognitive radio concept to military tactical systems, to analyze the pros and cons and to evaluate the benefits to the tactical communication systems. This presentation will review the main salient outcomes of the CORASMA program that include the different cognitive approaches implemented and the high-fidelity simulator developed within the program to assess the performance.

#### Workshop 7B Software Defined Radio 3

**Spectrum Intelligence for Interference Mitigation for Cognitive Radio Terminals**

Kresimir Dabcevic (University of Genoa, Italy), Muhammad Ozair Mughal (University of Genova, Italy), Lucio Marcenaro (Università degli Studi di Genova, Italy) and Carlo S Regazzoni (University of Genoa, Italy)

Cognitive Radio (CR) is defined as "a radio that is aware of its surroundings and adapts intelligently". While CR technology is mainly cited as the enabler for solving the spectrum scarcity problems by the means of Dynamic Spectrum Access (DSA), perspectives and potential applications of the CR technology far surpass the DSA alone. For example, cognitive capabilities and on-the-fly reconfiguration abilities of CRs constitute an important next step in the Electronic Warfare (EW). They may enable the jamming entities with the capabilities of devising and deploying advanced jamming tactics. Analogously, they may also aid the development of the advanced intelligent self-reconfigurable systems for jamming mitigation. This work outlines the development and implementation of the Spectrum Intelligence algorithm for Radio Frequency (RF) interference mitigation. The developed system is built upon the ideas of obtaining relevant spectrum-related data by using wideband energy detectors, performing narrowband waveform identification and extracting relevant statistical parameters. The recognized relevant spectrum activities are then continuously monitored and stored. Coupled with the self-reconfigurability of various transmission-related parameters, the spectrum intelligence is the facilitator for the advanced interference mitigation strategies. The implementation is done on the Cognitive Radio coaxial test bed architecture. Test bed consists of two Software Defined Radio (SDR) Secure Wideband Multi-role - Single-Channel Handheld (SWAVE HH) terminals, each interconnected with the computationally powerful System-on-Module (SoM) embodied with a Digital Signal Processor (DSP) and a Field Programmable Gate Array (FPGA). SWAVE HH is a fully functional SDR terminal operable in Very High Frequency (VHF) and Ultra High Frequency (UHF) bands, capable of hosting a multitude of both legacy and new waveforms. Additionally, it provides support for remote control of its transmit and receive parameters via the Simple Network Management Protocol (SNMP). Most of the signal processing is delegated to the SoM. After each predefined number of seconds, SWAVE HH outputs a burst of samples from its Analog-to-Digital-Converter (ADC) over the serial port to the SoM. There, the samples, corresponding to 120MHz around the center carrier frequency of the radio, are transformed into the frequency domain using the Fast Fourier Transform (FFT), and are analyzed by the implemented Energy Detector (ED). ED performs thresholding and, by employing the maximum likelihood decision rule, identifies a number of frequency regions, corresponding to narrowband waveform candidates, from the original wideband signal. Each of the identified candidate narrowband waveforms is then analyzed by the Feature Detector (FD). Namely, their maximum amplitude, center frequency and bandwidth are extracted and then compared to the features of the waveforms pre-stored in the database, eventually classifying them as either a "known" or an "unknown" waveform. Information pertaining to all the identified waveforms in the system, along with the results of their classification, and in addition the information about the currently observed spectrum holes, is then sent to the Spectrum Intelligence (SI) algorithm. SI algorithm keeps track of the occurrences of "known" and "unknown" waveform transmissions for each of the identified channels-of-interest, and subsequently triggers the corresponding action. For the simplicity purposes, we consider all "unknown" waveforms as "potentially malicious", i.e. corresponding to waveforms created by the jamming entities. SI invokes the proactive channel surfing whenever the "unknown" transmission is taking place on a carrier frequency close to the carrier frequency currently used for the transmission. SI chooses a new transmission frequency based on the identified spectrum holes, as well as the recent history of occurrences of identified "potentially malicious" waveforms in these spectrum holes. The new transmission frequency is instantly invoked by issuing the appropriate SNMP "change RF channel" command, both to the transmitter and to the receiver side. Both "known" and "unknown" signals are created and injected into the channel using the Vector Signal Generator using a pre-defined pattern. Signals powerful enough to significantly degrade the communication quality are considered. Degradation of communication link is measured by the "Link quality metric" - a Quality-of-Service (QoS) metric built-in within the SWAVE HH, which is directly related to the instantaneous Packet Error Rate (PER). The performance of the proactive channel surfing based on SI is evaluated as the percentage of time slots where successful transmission is taking place (Link quality is over the pre-defined acceptable threshold) over the percentage of time slots where transmission is considered jammed (Link quality is under the pre-defined threshold). The experiments were performed for varying number of non-overlapping channels (from 2 to 10), and varying patterns of the created interference (emulating varying complexity of the supposed jammer). The contributions of this paper are multi-fold, and may be summarized as follows: Implementation of Energy Detection based spectrum sensing algorithm is presented, which serves as the basis for the developed Feature Detection algorithm. FD continuously outputs the categorized waveforms to the Spectrum Intelligence algorithm, whose role is creating and maintaining spectrum awareness, and maintaining interference-free communication by means of proactive channel surfing scheme. The implementation of all the algorithms is done on the real-life SDR/CR platform, consisting of SDR RF front end coupled with the SoM, which is in charge of all the signal processing. Future work will focus on the development of more complex feature detection algorithm, which will be able to extract more relevant and precise (cyclostationary) features of the detected waveforms. In addition, since different waveforms exhibit different anti-jamming properties, dependent mainly on the employed modulation and bandwidth, Spectrum Intelligence algorithm will be embodied with more advanced anti-interference strategies, namely with options of switching between different waveforms, as well as altering transmission power.

**Experimental Study of Spectrum Estimation and Reconstruction based on Compressive Sampling for Cognitive Radios**

Muhammad Ozair Mughal (University of Genova, Italy), Kresimir Dabcevic (University of Genoa, Italy), Gabriele Dura (University of Genoa, Italy), Lucio Marcenaro (Università degli Studi di Genova, Italy) and Carlo S Regazzoni (University of Genoa, Italy)

Software Defined Radio (SDR) is a communication device in which some or all of the physical layer functions are defined in software. Traditionally, Cognitive Radio (CR) is assembled upon SDR. CR is a technology that allows unlicensed users to access the licensed frequency bands opportunistically. Hence, spectrum awareness is of prime importance for CR terminals. Spectrum awareness, in addition to open database (as in IEEE 802.22), typically comes from spectrum sensing which can be achieved by means of different methods, for example, matched filter detection, cyclo-stationary detection or energy detection. Matched filter is a coherent detector and requires a priori information of the licensed user signals thus increasing the CR complexity. Cyclo-stationary detector make use of some of the inherent properties of the licensed users' signals and uses computationally complex algorithms to identify the spectrum holes. Energy detector is a non-coherent or blind detector which only measures the energy of the received signal, and takes decision on spectrum availability after comparing the measured energy with a predefined threshold. Each of these methods has its own pros and cons, however, energy detection appears as a preferred choice for CRs with limited computational power, due to their low implementation complexity. Lately, there has been much interest shown by researchers on the analysis of energy detectors both in narrowband and wideband regimes. Nevertheless, the task of spectrum sensing becomes increasingly difficult for wideband signals. It is because the receiver requires to sample the wideband signals at or above Nyquist rates. This requires very high-rate analog-to-digital converters (ADC) which increases the cost of the CR terminals. To overcome this shortcoming, compressive sampling (CS) has stormed into the signal processing research for the purpose of spectrum estimation and reconstruction. Literature on CS shows that a sparse signal can be recovered from random or random like samples taken at sub-Nyquist rates. Due to low spectrum occupancy by licensed users, the signals in CR networks are typically sparse in the frequency domain. Recovery using CS requires intense, non-linear optimization to find the sparsest solution. One solution to this is by means of Convex Programming as in Basis Pursuit (BP) method. BP is a technique for decomposing a signal into an optimal superposition of dictionary elements and the optimization criterion is the L1-norm of coefficients. The other solution is the usage of Greedy Algorithms, such as Matching Pursuit (MP) and Orthogonal MP (OMP). For instance, MP iteratively incorporates in the reconstructed signal the component from the measurement set that explains the largest portion of the residual from the previous iteration. OMP additionally orthogonalizes the residual against all measurement vectors selected in previous iterations. This work addresses the applicability of CS approach to spectrum estimation and reconstruction to real world communication data acquired from a wideband SDR based hand held military radio (SWAVE HH or HH). For these purposes, a test bed was assembled for a frequency range of interest, consisting of a HH interconnected with the PC; vector signal generator; and the corresponding auxiliaries. Agilent E4438C signal generator is used to generate various real-world, as well as custom, wideband and narrowband signals. The signal generator is connected to Agilent 778D 100MHz - 2GHz dual directional coupler with 20 dB nominal coupling, by means of a coaxial RF cable. Use of coaxial cable allows us to repeat the experiment under same conditions, eliminating uncertainties of wireless transmission. HH is a fully operational SDR transceiver capable of processing various wideband and narrowband waveforms. Its 12-bit analog-to-digital converter (ADC) performs the sampling of incoming signals at very high rates of 250 Msamples/sec, and HH is capable of scanning 120 MHz of wideband. The digitized signal is then issued to the FPGA, where it undergoes down conversion, matched filtering and demodulation. Several interfaces are available on the HH, namely, 10/100 Ethernet, USB 2.0, RS-485 serial, DC power interface and PTT. SWAVE HH was connected to the PC by means of Ethernet, as well as serial port. Ethernet is used for the remote control of the HH, using Simple Network Management Protocol (SNMP) while serial connection is used for transferring the spectrum snapshots from HH to PC. Also since the data transfer rate of the serial port is low, i.e., 115200 bits/s, real time transfer of samples is not possible from the ADC of HH. For this, 8192 samples are transmitted from the ADC over the RS-485 serial port every 3 seconds, a functionality hard-coded in the HH's FPGA. Intrinsically speaking, the output of ADC contains raw samples of the spectrum. These raw samples are stored in a buffer internal to the FPGA and output through HH's serial port to the PC, where they can be processed. Since 8192 samples make the waveform analysis a difficult task due to the low frequency resolution, multiple snapshots of the spectrum are taken and analyzed at once. Once that the satisfying number of samples is collected and transferred to the PC, CS may be performed. For the demonstration purpose, we choose to implement a conventional CS approach, i.e., Basis Pursuit (BP). To find the sparsest solution, BP requires to solve the complex optimization problem for an underdetermined system of equations. The Primal-Dual (PD) interior-point method solves this convex optimization by using the classical Newton Method. Performance of the scheme was evaluated for different values of compression rates. It was shown that through application of CS, sub-Nyquist rate sampling can achieve good signal reconstruction. This is particularly useful because it can reduce the cost incurred on high rate ADC. In the end, energy detection on the reconstructed waveform is applied to quantify the detection performance under different compression ratios. Future work will include connecting two more SWAVE HH at the input and scanning the real-world communication waveforms from these HHs. Furthermore, a study and implementation of collaborative spectrum sensing algorithms based on the CS framework will be analyzed and implemented, allowing for more reliable detection of spectrum holes in wideband regimes, thus further improving the overall spectrum utilization.

**LibLTE - a Modular Open-Source LTE Library for General Purpose Processors**

Paul D Sutton (Trinity College Dublin, Ireland) and Ismael Gomez-Miguelez (Trinity College Dublin, Ireland)

The open-source LibLTE library provides the building blocks required to implement 3GPP LTE and LTE-Advanced waveforms using general-purpose baseband processors and RF front-ends. The modular design of the library emphasizes usability and minimizes external dependencies, making it suitable for use in applications ranging from basic downlink scanners to fully-functional eNodeB implementations. Both high and low-level APIs are provided, simplifying the use of libLTE in component-based SDR frameworks such as GnuRadio, ALOE and Iris while also supporting tightly-coupled standalone application development. This paper provides an overview of the library, describing the functionality currently supported and outlining the roadmap for future development. Example applications are presented and the potential for using libLTE in future CloudRAN architectures is discussed.