

Cognitive Radio Platforms for Disaster Response Networks, Survey

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Abstract

Either natural or man-made a disaster is defined as unexpected destructive event that causes damages and malfunction of existing systems and services all around the disaster area, these destructive effects are unfortunately beyond the capability of local authorities to recover and respond immediately, the disaster recovery plans are immediately initiated so that rescue and aid operations can help those who are trapped in disaster area to survive, those efforts need to be controlled and coordinated with reliable communication systems that are more likely partially or fully disabled due to the disaster, the capabilities of cognitive radio technology enables it to play a significant role in providing efficient communication services for the rescue teams and headquarters as well as trapped victims, in this paper, we survey the cognitive radio architectures that can replace the Software Defined Radio SDR in order to reduce the network expenses in terms of network size and network computational complexity.

Keywords: Cognitive radio, disaster response networks, cognitive radio platform.

1. Introduction

As a promising technology, the cognitive radio CR technology was introduced first by Joseph Mitola [1], Mitola introduced this technology as a smart communication technology that has the ability to adapt its communication parameters according to the information sensed from the communication environment, Mitola described CR technology with its high-level cognitive capability and routing parameters adaptation, to prove this, he utilized a Personal Digital Assistant PDA device equipped with CR capabilities and could use this device for intelligent communication that fulfilled user requirements [2]. This concept was later extended and used to establish communication links at lower

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levels of the radio spectrum and radio stack. The implementations of CR technology also included the physical (PHY) layer aspects and rapidly grew due to CR's most powerful feature which is dynamic spectrum access (DSA). To efficiently introduce the CR technology history and applications [3], the features of CR technology involved enormous topics that are all related to efficient utilization of spectral resources, signal management, spectrum sensing, network intelligent management, AI implementations and many other aspects. The implementation of CR technology was made easier with the availability of reliable network simulation tools such as NS2, OpNET, MATLAB or customized dedicated simulators. The concept of Software Defined Radios SDR also played a major role in this domain.

The cognitive radio technology is directly concerned with the radio spectrum which is considered the extremely precious resource for all wireless communication systems, it is the portion of the radio spectrum whose frequencies range from 30 Hz to 300 GHz. The waves in this frequency range which are basically electromagnetic waves are the backbone of almost all modern wireless technologies, particularly in telecommunication systems, the interference between these frequencies is strictly regulated by the international telecommunication union ITU, that is why this resource is a limited resource and utilizing it requires excessive authorization procedures, furthermore, the wireless services have proliferated in the last decades which add more and more load to the consumption and utilization of radio spectrum, in the same time, most of the available radio spectrum is already reserved and its bands are already assigned to organizations and telecommunication organizations, this resulted in a common problem known as spectrum scarcity [4].

The CR technology is all about efficient utilization of available spectrum bands due to its DSA, the radio frequencies are dedicated to Primary users PUs that are the licensed users, the CR enables another category of users referred to as secondary or cognitive users CUs to opportunistically utilize the radio frequency bands that are dedicated to PUs at the times when the PUs are idle or not active, these frequencies are known as TV white spaces [5, 6]. Furthermore, Due to their dynamic nature, CRNs enable the transmission of real-time data traffic. transmitting multimedia content over CRNs is a challenging task [7, 8, 9]. To support critical data without delay such as in military and industrial applications, the CR was empowered with many features regarding their architectures, routing schemes, sensing mechanisms, interference avoidance and routing protocols, the CR can also help in providing seamless multimedia communications in the limited spectrum resources by utilizing the available radio spectrum bands while the PU is inactive [10].

At the time of disaster, a quick and synchronized response must be given to the rescue and relief entities, the first responders and victims present in the post disaster scenario. Another important action is to save the lives as much as possible, meet the needs of the victims and minimize the losses due to the disaster. The data collection and analysis of the disaster affected area are one of the most important necessities to deal with injured victims, loss of lives and damage of properties, the obtained information is helpful to the main coordination center of the rescue and relief operation to coordinate and manage the resources [11].

From a technological Perspective, disaster can be defined as a large scale malfunction, disability or temporary damages of the existing communication infrastructure of communication or telecommunication systems, this can temporarily or permanently prevent access to standard wireless or wired telecommunication services and also the internet access, these services in such a situation are extremely important and can aid in saving lives of people trapped in disaster area, without the availability of reliable communication services, the first responders and relief workers cant coordinate rescue efforts or even initiate those efforts, based on its origination, disasters can be classified into two main types that are:

Natural disasters: referred to natural and physical phenomenon that emerge due to slow long-

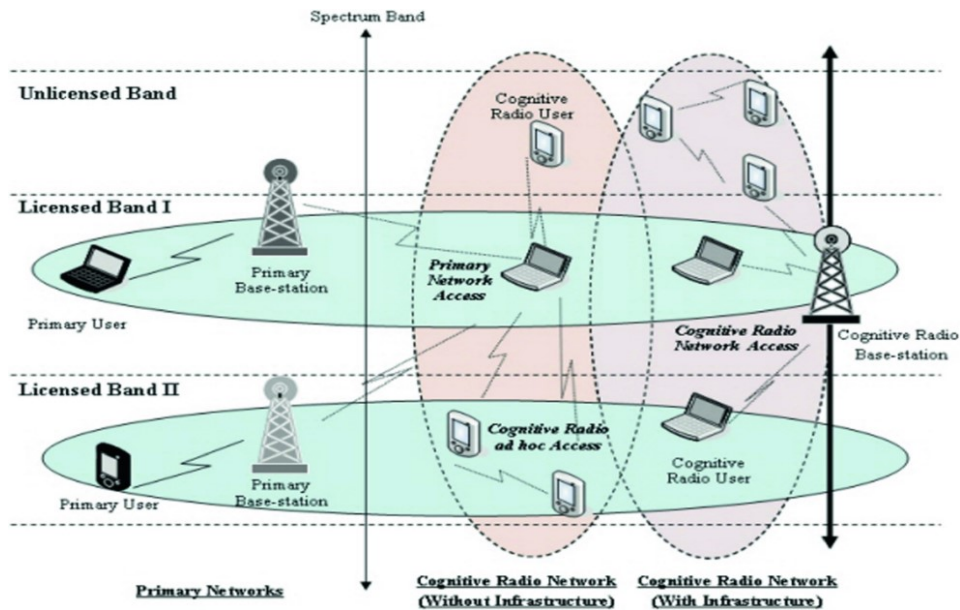


Figure 1: The Cognitive Radio Concept.

term events happen in nature that can be geophysical such as earthquakes, tsunamis, landslides or volcanos, they can be also hydrological, climatological, meteorological or biological such as floods, temperature, cyclones, and epidemics respectively.

Technological or man-made disasters: majorly result from human mistakes in factories or facilities resulting in explosions or fires in the surrounding areas specially if these facilities are located in human occupied places, other reasons are possible traffic accidents or damages in properties due to human mistakes.

2. Software Defined Radios SDR

One of the methods for utilizing the capabilities and functionalities of CR is through the usage of Software Defined Radios, Software-defined radio (SDR) is the concept of implementing communication systems on software tools rather than building these systems using hardware components for the sake of network simulations and construction of testbeds [12]. The concept of SDR is not recent, it was used by research community for many years, the rapid advancements in digital electronics resulted in many theoretically possible digital systems but are hard to be implemented and manufactured due to unavailability of the required digital components or even their high costs, a simple SDR system may involve a simple personal computer equipped with a form of radio frequency RF front end connected to a digital sound card or analogue-to-digital converter, this makes it possible for all sound processing operations to be conducted over the general purpose processor of the personal computer rather than attaching a dedicated processor in conventional communication systems [13].

Most cognitive radio based prototyped systems are constructed using one out of two common radio platforms which are (i) The Universal Software Radio Platform (USRP) series introduced by Ettus Research institute [14] which is most commonly used platform in PHY layer applications, and; (ii) the Wireless Open-Access Research Platform (WARP) introduced by Rice University [15] which is most commonly utilized by networking researchers and research institutes. Both can be used when connected to personal computers and laptops with powerful enough computational powers, some system engineers prefer to design and develop their own customized hardware platforms for

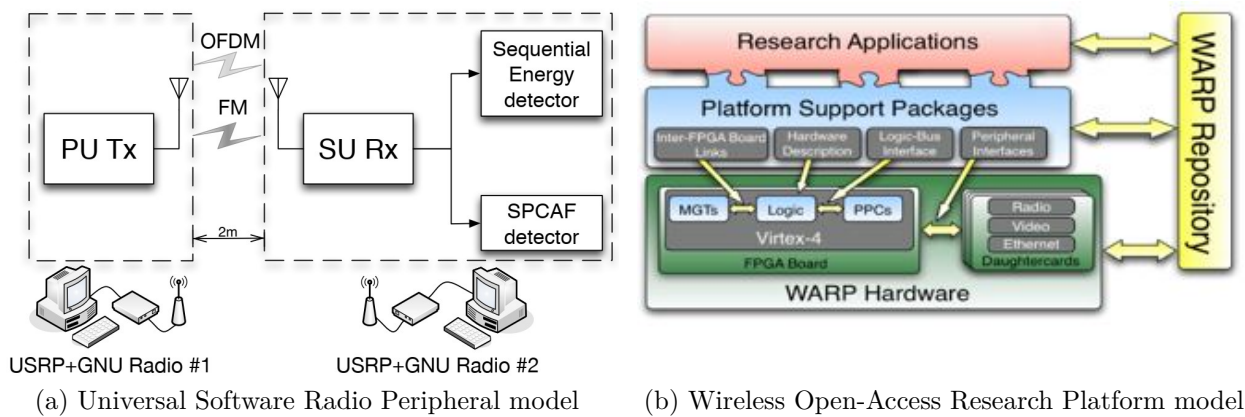


Figure 2: common DSR platforms.

CR research such as the Berkeley Emulation Engine (BEE) and CR Learning Platform (CORAL) for experimenting and evaluating the performance of their proposed techniques and algorithms.

There was always a direct connection between the CR technology and the SDR technology since the emergence of both the technologies; the truth is that the CR initial dissertation presented the CR technology as an extension of SDR. The SDR was used in the early proposals for practical CR applications where an architecture in which an intelligent software-based tool produced by CE enterprise controlled an SDR. At that time, the SDR technology was a new technology, the first practical SDR prototype used a flexible configurable hardware radio. But the rapid advancements in this domain quickly introduced reliable SDR packages such as GNU Radio, IRIS, OSSIE, etc., which are considered as cheap reliable platforms on which CR applications can be run. Since then, a CR application usually involved an SDR solution.

2.1. Limitations of Software Defined Radio for Cognitive Radio Networks

Different perceptions are there about SDR and their design and implementation fundamentals, some engineers believe that SDR are favored from other CR platforms, while others believe that SDR have some limitations that make them unreliable for implementing CR based solutions for various communication systems [16], this difference comes from the fact that CR based communication theorists consider the radio as a group of blocks in series executing different mathematical instructions, this belief results from their being unaware of issues like spurious response, dynamic range, bandwidth, etc., while radio frequency engineers believe that an SDR is not a real computer system that performs that real time calculations on which the processing of analogue communication is based due to the fact that analogue signals are composed of a continuous sequence of signals transmitted in a chain, so it is difficult to process the current block of signal fragments in a real-time manner and gets ready for the next block of signals, engineers believe that this is such a really challenging task for SDR specially because they are performed using conventional computers [17].

Software defined radios offer certain significant capabilities for CR-based communication systems design, these capabilities include potentially unlimited reconfigurability and the ability to build new components, but it also suffers from certain drawbacks such as overhead, resource consumption, and time delays at the time of reconfiguration . These limitations are significant. For many applications of SDR, they are parts of real-time systems, requiring hardware platforms and tools and expertise that the engineers who are working on these tasks are unaware of. the system is all about hardware and software, the mismatch between them may limit the performance of the SDR-based communication

system, this mismatch may drive the system to simply select its modulation sets and parameters from a small set of preprogrammed parameters and modulations, this can simply produce a radio with serious limitations in terms of cost, reliability as compared to single board transceivers [18].

2.2. Classification of CR platforms

Designing and deploying a CR platform requires flexible hardware and software solutions. Different types and structures of CR platforms are discussed in this section, these platforms can be categorized into three main categories, The criteria of classification is basically due to extent up to which these packages and platforms are utilized, these categories are [19]:

1. Reconfigurable platforms (SDR based).
2. Composite platforms (Hardware & SDR based).
3. Standalone platforms (Hardware based).

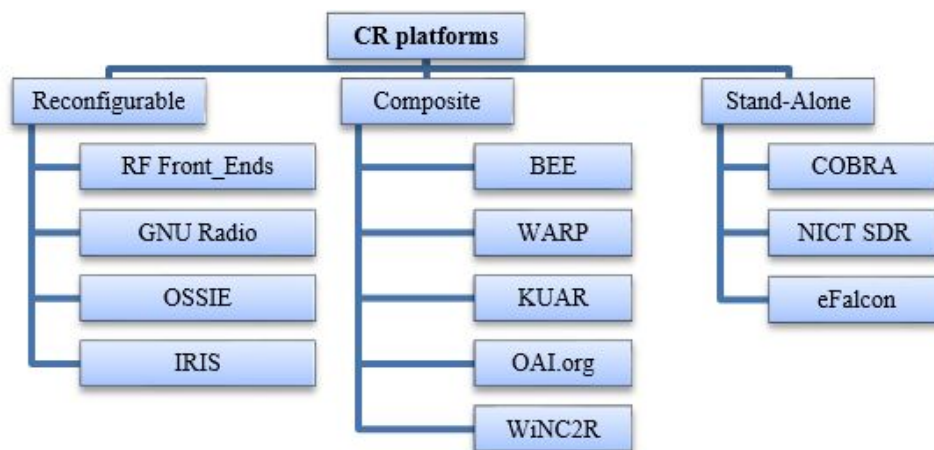


Figure 3: classification of CR platforms.

2.2.1. Reconfigurable platforms

As their name implies, these platforms are based on software defined radios, they are allowed to be reconfigured according to the radio environment, They are research systems introduced by Iris, GNURadio and OSSIE that are in turn developed under GNU Licenses.

RF Front-Ends . Refers to Radio Frequency front ends, although these platforms are required to perform all signal processing instructions based on software, they still need to be equipped with minimum RF front-end hardware. the Universal Software Radio Peripheral (USRP) is the most used platform by CR research community because it is an inexpensive RF front-end, it also comes with an acquisition board with an open board design and its documentation and schematics are available for free. It can also be extended so that different RF slave boards for other frequency ranges can be connected to the main board.

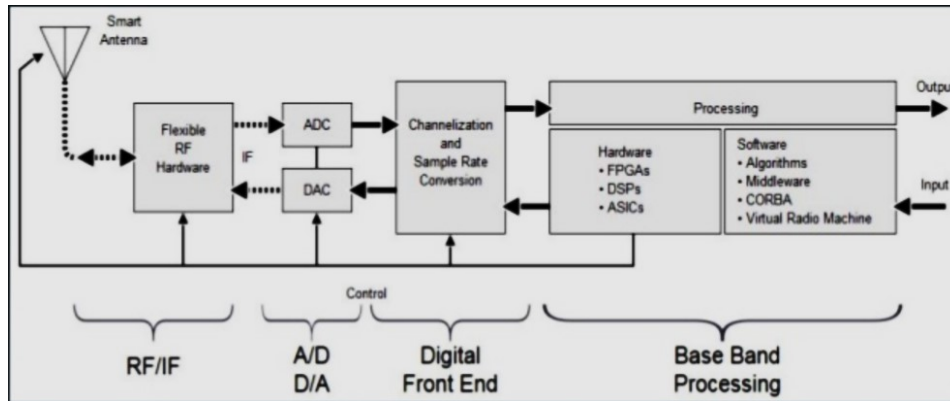


Figure 4: RF front-End architecture.

GNURadio Platform . In conjunction with the development of the GNU Linux project, the GNURadio platform was introduced which was required as an open-source Unix-like operating system, it stands for GNU’s Not Unix, it is considered a very useful platform since it provides a large variety of digital signal processing DSP libraries. The GNU General Public License provides all these libraries and packages for free [20]. The aim of designing this platform was the ability of working on software defined radios (SDR) in a real time environment so that the radio layout is highly flexible, this platform encounters a large numbers of blocks such as filtering elements, equalizers, synchronization elements, channel codes, digital and analogic demodulator, decoder, FFT block and other elements, it also produces distinct signal processing algorithms and including the newly obtained algorithm as new blocks in the major design, that is why this platform provides a very flexible environment for research community.

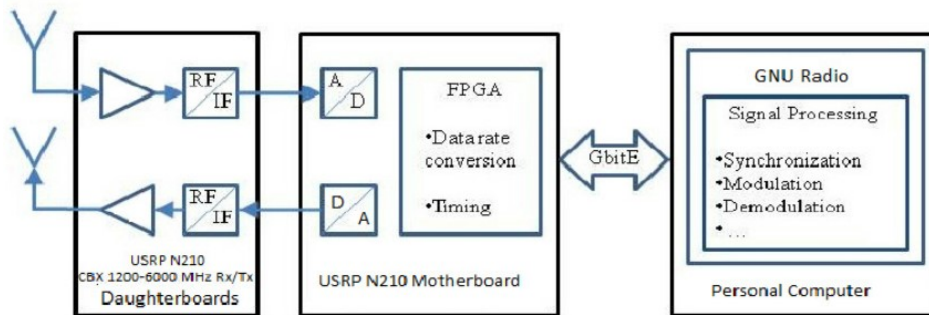


Figure 5: GNURadio block diagram.

Since all signal processing instructions are performed using the host PC, the processor of this PC can control the functions of SDR to process, detect, syntonize, fetch and record radio signals. But still it can be used without the need to any hardware components when used to simulate wireless communication systems [21].

OSSIE Platform . Refers to Open Source Software Implementation::Embedded, this platform was introduced to support educational tasks and research projects related to SDR as well as CR, distributed wireless computational applications, and security, it was basically developed for Linux platforms. It is also possible to use Cygwin or VM workstation to run such a platform using Microsoft Windows OS and other platforms [22], OSSIE development also involved some debugging tools to visually support the prototyping of OSSIE-based systems, OSSIE Waveform Work-shop refers to

the full set of tools and libraries. It also contains the OEF (OSSIE Eclip Feature), OWD (OSSIE Waveform Developer) and ALF (Action Language and FUMML) systems.

IRIS platform . This platform was introduced by Dublin University, Trinity College, it refers to InterSystems and provides the developers with a full data platform enabling them to select their preferred programming language along with their preferred model of data out of many languages and models supported, this makes it a soft-ware radio framework that can be dynamically reconfigured, a general purpose processor comprises the system while a radio component written in C++ comprises the essential building block of the system by which one or more stages of a transceiver chain implements can be implemented, furthermore, it is possible to specify the chain of signals construction and their characteristics using the XML language.

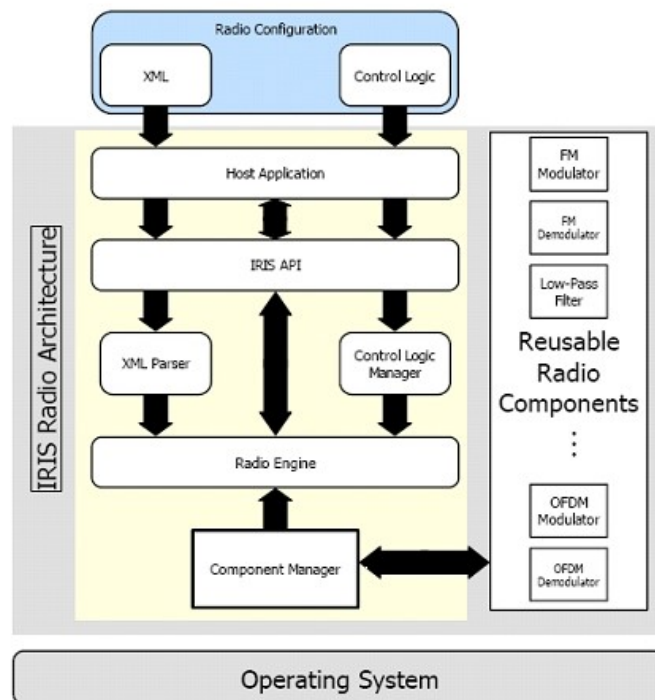


Figure 6: IRIS Platform Architecture.

The IRIS platform also provides processing algorithms that can be dynamically configured for shaping the waveforms to efficiently utilize the available TVWS. The spectrum utilization problem between two communicating parties that are anonymous for each other can be processed using dedicated IRIS components, the IRIS system also provides multiple algorithms for sensing, these algorithms are for simple energy detection and are reliable since they use filter banks [23].

Composite Platforms . Also referred to as hybrid platforms, the operation of such platforms involves both SDR and hardware implementations, these platforms are mainly characterized by their capability to be dynamically reconfigured. In terms of CR operations, composite platforms contain all the components required for CR-based application development [24]. The following section illustrates these platforms.

Berkeley Emulation Engine (BEE) platform . This platform was developed by the University of California at Berkeley Wireless Research Center, it is a general purpose platform that has the

capability to perform up to 500 Giga of instructions per second, this can be achieved with distributing those instructions on multiple Field-Programmable Gate Arrays FPGAs involved in this platform, and, its operation environment is a multiuser environment similar to that environment of conventional PC that allows users to share available computing resources while keeping the overall throughput of this system stable. The architecture of the BEE hardware is so simple since it is composed of low-cost and commercial components, it is important to mention that this platform is a demonstrator, that means it doesn't have the capability of mass production and throughput [25].

Wireless open-Access Research Platform (WARP) . This platform was developed by the Rice University, Houston in Texas it is an SDR platforms that is characterized with its scalability, programmability and extensibility, SDR [15]. The aim of designing this platform was to open the hardware components as well as software components that are required for building and prototyping next-generation wireless networks and enable research community to explore their proposals in developing and prototyping next generation networks. The hardware components used to build the USRP platform are also used to build the WARP platform, these components use FPGAs for Digital Signal Processing DSP optimized development to scale a number of FPGAs required to produce an increased computational power as required, the block diagram for WARP is shown in Figure 2 B.

Kansas University Agile Radio (KUAR) platform . The name of this platform tells that this platform was developed by university of Kansas, KUAR is a 5.25 to 5.85 GHz board that is used for experimental analysis of digital communication systems, the infrastructure of this platform is an unlicensed national information infrastructure [26]. The main component of this platform is the Xilinx Virtex II Pro P30 FPGA circuit with built-in PC responsible for performing the tasks of signal processing, independent interfaces are used to connect the FPGA to the embedded 1.4GHz general purpose processor allowing batch processing between the FPGA platform and the embedded PC. KUAR platform handles gigabit Ethernet and PCI express connections back to a host computer. This enables the platform itself to perform almost all the operations without the need to the PC processor and hence, minimizing the load on the host interface communications. The platform main board is battery powered so that it provides untethered operation. Furthermore, KUAR signal processing features are done using modified form of the GNU Radio software framework [27].

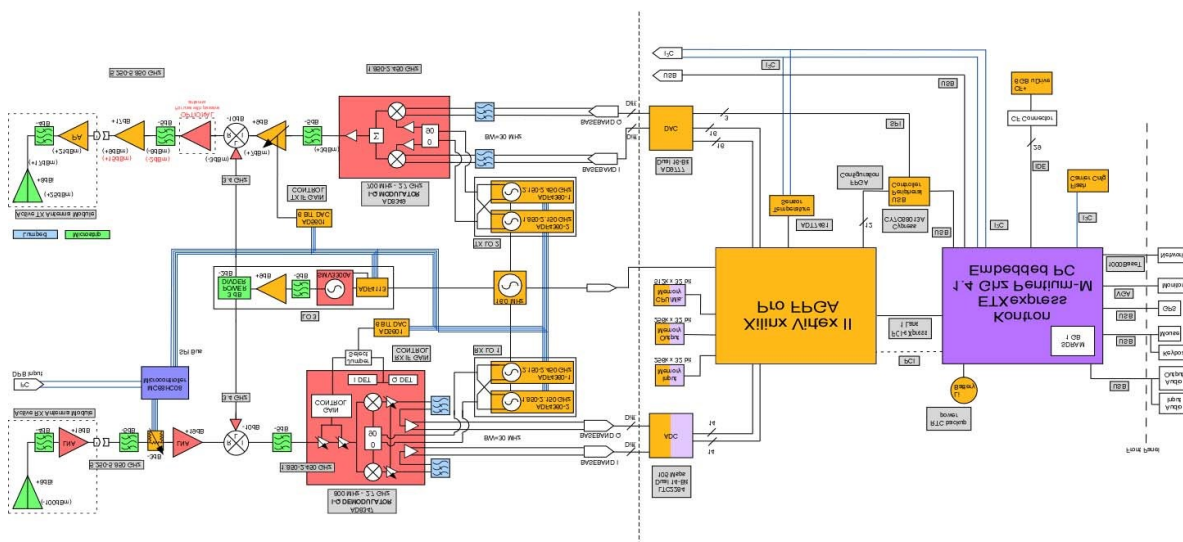


Figure 7: KUAR System Diagram

OpenAirInterface.org . The Mobile Communications Department at EURECOM OpenAir Interface (OAI) developed this platform for the task of experimentation and prototyping enabling research projects and innovative technologies in the domain of wireless communications [28]. PC and FPGA-based equipment are combined in a generic architecture enabling this platform to identify network devices based on their designated IP addresses using all open-source tools and software development environments. Two high density Xilinx Virtex 5 FPGAs: LX110T are used for interfacing the PC based system with LX330 FPGA forming a signal processing engine, the resulting platform can function as standalone platform. The card on of the prototype contains converters connected to an external RF providing MIMO input/output capacity of 8x8 [29].

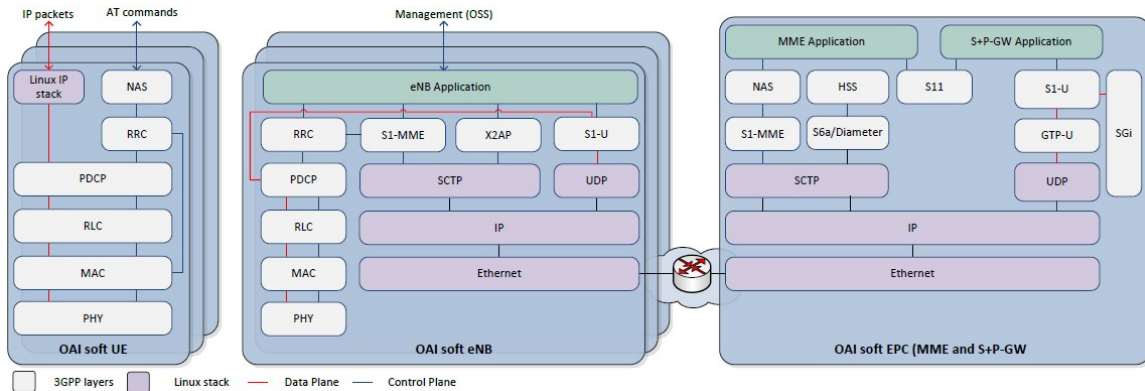


Figure 8: OpenAirInterface LTE software stack.

WiNC2R . This platform is a cognitive radio-based platform that was developed by WINLAB institute at Rutgers University, the aim of developing this platform is to address the issue of workload characteristics of wireless communication protocols that are controlled by programming, the architecture of this platform involves both hardware and software modules uniformly to cope with functional as well as performance requirements. The workload characteristics along with functional specifications of radio communication protocol processing applications are satisfied using Virtual Flow Pipelining (VFP) architecture approach [30]. The main characteristics of workload are the following:

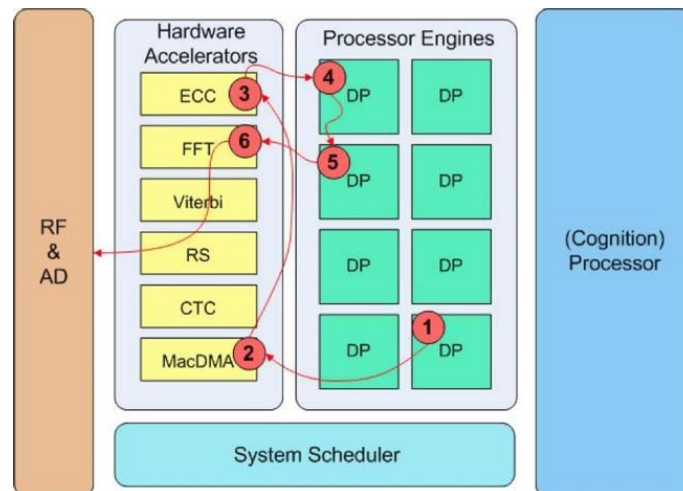


Figure 9: WinC2R hardware components.

- Hardware is controlled on a system level to support the flow requirements of the protocol processing, other functions like synchronization and scheduling are also controlled.
- Generic hardware modules along with software programmable instructions form the functional units and are controlled by the system level VFP controller.
- Per-packet bases is used to switch functions for both hardware and software.
- Fast context switching is enabled and handled by central processing units which cancels the need for additional embedded operating systems [31].

The WiNC2R high-level architecture shown in Figure 9, which shows that the platform is also equipped with a baseband modem module having its own associated RF module [32].

2.2.2. Standalone platforms

The number of SDR hardware platforms equipped with RF front-end to support the development of CR platforms is limited [33], the hardware platforms commonly used to build CR platforms are illustrated in this section . in common, the components of standalone platforms implement the subset simulation (SS) algorithms [34] to efficiently utilize the available spectral resources with minimum levels of interference.

Cognitive Baseband Radio (COBRA) . The architecture of COBRA platform is oriented towards 4G requirements up to throughput of around 1Gbit/s with multiple asynchronized streams concurrently such as highspeed internet access along with simultaneous digital broadcasting reception. The custom nature of this platform enabled it to be suitable for standards like WLAN (IEEE802.11n to .11ac), cellular (LTE to LTE-advanced), and broadcasting (DVB-T/H to DVB-T2)) , the customization of this platform involves all cores of the platform according to the operational requirements and the standard targeted [35]. Furthermore, the elements of this platform are programmable using C or higher-level assembly languages. The platform also features a novel application-specific integrated processor ASIP-based digital front-end for synchronization of filtering and radio spectrum sensing. ASIP also supports hierarchical platform activation required for idle power in the range of 2mW in 65 low-power CMOS technology for the baseband platform [36].

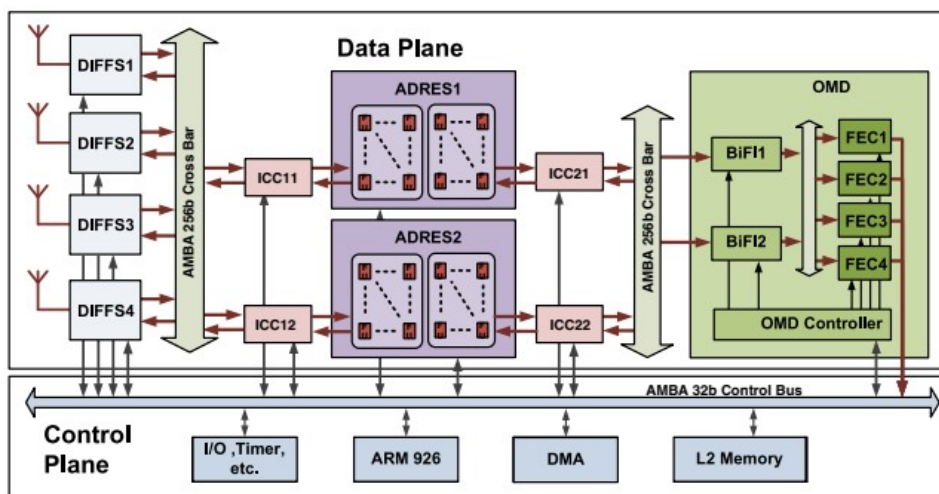


Figure 10: IMEC COBRA platform architecture.

NICT SDR platform . This platform was developed by (NICT), the Japanese National Institute of Information and Communications Technology, this platform is an SDR-based platform dedicated to trial next generation mobile networks, the platform can support communications ranging from 1.9 to 2.4 and 5.0 to 5.3 GHz, this powerful performance is due to the fact that this platform is equipped with four Xilinx Virtex2 FPGA, RF modules and two embedded processors, the architecture of this platform is shown in Figure 11.

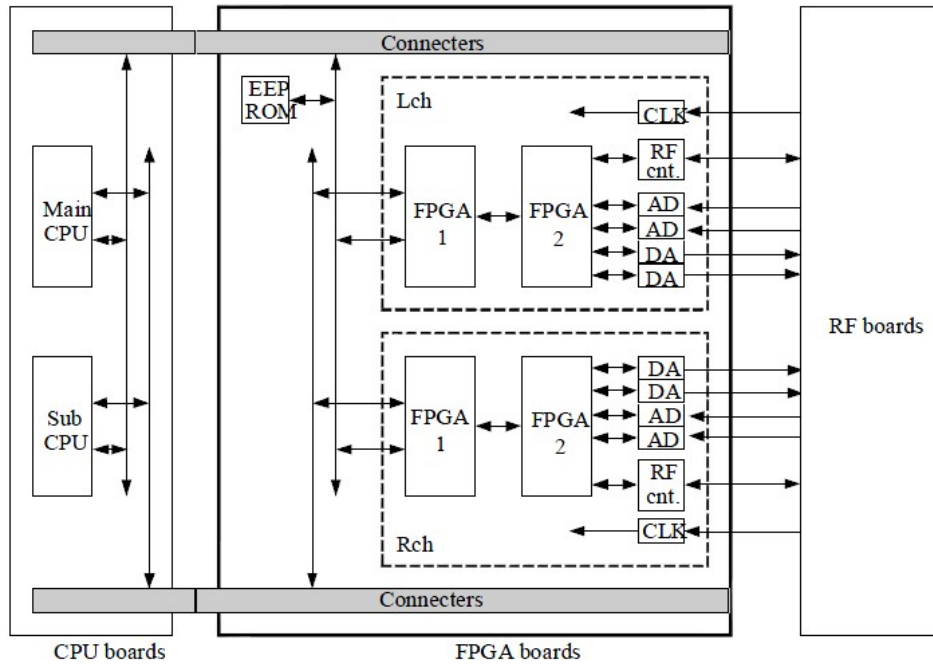


Figure 11: Configuration of NICT SDR platform.

This platform aims to explore the selection algorithms as the main objective which in turn helps in managing the handover between various existing standards. Standards such as, for example, 802.11a/b/g, digital terrestrial broadcasting, WCDMA, and OFDM communication scheme were implemented in this platform [37].

eFalcon Platform . This platform was developed in 2011 by University of Duisburg-Essen in Germany and is characterized with its flexible hardware-based CR components [38], the core components of this platform contain triple-core digital signal processor (DSP) with system clock up to 1 GHz in conjunction with FPGA [39], to resolve the weakness of debugging the signal processing algorithms implemented on the platform, the DSP processor data rate is doubled up to DDR2- 256MB RAM enabling the running and implementation of applications requiring intensive processing capabilities, the platform involves multiple serial high speed adapters such as GB ethernet link, three full-duplex buses forming the antenna interface, and finally, a Serial Rapid Input Output (SRIO) link. Furthermore, eFalcon combines the features of both digital processors and programmable logic, this combination supports real time operation.

3. Conclusion

The cognitive radio technology provides an innovative approach for the design and implementation of modern and advanced communication systems that can provide reliable services to its users, the

research on future networks involves the implementation of this technology to empower the next generation communication system, an extremely important scenario where these networks are highly applicable is emergency, public safety and disaster response networks, in this paper, we have provided an exploratory study on various CR platforms and testbeds that are applicable in such a harsh scenario, it is clear that composite (Hybrid) platforms allow the evaluation of new SS algorithms that can enhance the overall network performance, they involve the advantages of both reconfigurable and standalone platforms, hence; the composite CR platforms are more likely to be implemented in disaster response networks specially because other platforms such as WiNC2R and COBRA, are currently in internal use only.

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