Software Defined Radio Certification in Europe: Challenges and Processes

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*Abstract***— Standardization and certification of Software Defined Radio technologies are closely related. This paper describes the current standardization efforts for Software Defined Radio technologies in Europe and the related certification processes with a specific focus to the public safety and military domain. This paper describes the regulatory and technical requirements for the certification of Software Defined Radio in the European context, which is characterized by various political entities and governmental institutions. We describe the development of an European Software Defined Radio certification process through a networked approach and we identify the main components including the Development and Testing tools, References Implementation, the Waveform Repository and the Issue Tracking system. The main stakeholders in the certification processes are identified and their roles are described. This paper describes also two specific certification processes, which are particularly important for Software Defined Radio technology: performance benchmark certification and security certification. Performance benchmark certification is used to evaluate the performance of Software Defined Radio against specific technical requirements. Security certification is needed to ensure that the Software Defined Radio platform and the waveforms validate security requirements. The conclusion is that Software Defined Radio certification at European level requires a comprehensive framework, which includes organizational, procedural and technical elements[1].**

Keywords - Software Defined Radio, Certification, Performance Benchmarking

I. INTRODUCTION

The concept of Software Defined Radio dates back to the 1992 when Joseph Mitola described it in [2].

For a number of years the focus of software defined radio (SDR) research was on military applications. The JTRS (Joint Tactical Radio Systems) program [3] and [4] is intended to permit the Military Services to operate together in a “seamless” manner via wireless voice, video, and data communications through all levels of command, including direct access to near real-time information from airborne and battlefield sensors.

JTRS is envisioned to function more like a computer than a conventional radio and is to be upgraded and modified to operate with other communications systems by the addition of software as opposed to redesigning hardware - a more costly and time-consuming process. A single JTRS radio with multiple waveforms can replace many separate radios, simplifying maintenance. The additional advantage is that because JTRS is "software programmable", they will also provide a longer functional life. Both features can offer potential long-term cost savings to the military organizations.

For the public safety community, SDR developments were primarily part of the internal research and development activities of land mobile radio vendors. The Public Safety domain was not the primary focus of SDR industrial vendors. However, several incidents over the past several years have suggested that public safety community may use evolving SDR and cognitive radio technology to address critical public safety communications challenges.

Interoperability has been a long-standing challenge in public safety communications. We have numerous examples in which responders with incompatible radios have been unable to communicate during a natural disaster or an emergency/crisis situation. The challenges of interoperability in public safety communication have been described by a number of sources including [5] and [6].

The application of SDR to mitigate or resolve interoperability barriers in the Public Safety domain has been the focus of the FP7 PASR WINTSEC project [7].

The WINTSEC (Wireless INTeroperability for SECurity) project aims to explore a mix of complementary solutions to overcome the barriers for wireless interoperability across different security agencies, taking into account the constraints of the security services and legacy systems and equipment. WINTSEC studies the deployment of standardized Internetworking layer at Core Network level and Software Defined Radio (SDR) added value for Base Station and Terminal. WINTSEC addresses information assurance, elaborates the European “SDR Architectural Framework” and the concepts for the “SDR Certification Environment”.

[1] the views expressed are those of the authors and cannot be regarded as stating an official position of the European Commission.

Certification of the equipment and software is an essential process in the Public safety or Defence domains. This is particularly important for the introduction of new technologies like SDR, which must be validated against specific operational and technical requirements.

Because of its high degree of reconfigurability and ease of programming, SDR is a technology enabler for cognitive radio (CR). Cognitive radio is a radio or wireless communication device that is able to change dynamically its transmission or reception parameters by using the information collected or sensed on the external environment. Cognitive radios can also potentially enable Dynamic Spectrum Allocation (DSA), where the allocation of spectrum bands to communication services can change depending on time and context (see [8] and [10]). The use of SDR as an enabler of CR makes the certification activity even more important, because a badly configured or faulty SDR can negatively affect other wireless communication services in the same coverage area through harmful wireless interference. The need for a certification process for SDR as a CR and DSA enabler, are described in [9] as part of the standardization work of IEEE P1900.3.

Reference [9], identifies four testing areas for certification:

- Over the Air. A Provisioning Testing, which verifies the ability of a device to correctly obtain & install applications over the air.
- Security Testing to ensure that security requirements are validated.
- Performance Testing to validate the time constraints and
- Stress testing to verify the robustness of the implementation when stretched to the limits of system resources.

The paper acknowledges that SDR certification is a difficult task because SDR is a complex system with a large potential state space. The validation and certification of non-functional attributes (e.g., security) is particularly challenging for SDR products.

The complexity of SDR certification is also discussed in [11], where the vast amount of SW and HW combinations is identified as one of the biggest challenge in the certification process.

A preliminary study on SDR standardization and certification is provided by the same authors in [1], but the paper does not address performance benchmarking and security certification, which is investigated in this paper.

This paper will provide a survey of the SDR standardization and certification status in Europe and a proposal for a SDR certification framework and related tools.

The paper is structured in the following sections: section II describes the status of SDR standardization and certification in USA and Europe with the identification of the main challenges. The certification framework is proposed in section III, which describes the main elements of the SDR certification process including the reference implementations, the certification of API compliance, certification tools, the structure of the certification network, the waveform libraries and the issue tracking workflow. Two specific certification processes are then presented in the following sections. Benchmark certification is described in section IV, while security certification is described in section V. Finally section VI concludes the paper.

II. SDR Standardization And Certification

The initial drive for standardization has been the JTRS program, which proposed the Software Communications Architecture (SCA) as a framework to integrate the hardware and software components.

SCA is a framework for developing SDR systems and we can define a framework as a set of cooperating classes that make up a reusable design for a specific class of software.

The interfaces among the classes and the other elements of the framework must be clearly defined to facilitate the activity of development, integration and validation.

The goals of the SCA are to:

a) provide portability of applications between different SCA implementations,
b) Reduce development time of new waveforms through the ability to reuse design modules;
c) Build on evolving commercial frameworks and architectures.

SCA is based on CORBA as a middleware to provide the communications among the main components and functions of the framework, which are:

- Radio management functions,
- Domain Manager,
- Application Factories,
- Applications,
- Device Managers and
- Devices

The portability concept is quite important for SCA and it is a basis for the certification process. SCA and SDR are mostly investigated in the Wireless Innovation Forum, which is (from reference [12]):

"Established in 1996, the Wireless Innovation Forum™ is a non-profit international industry association dedicated to promoting the success of next generation radio technologies. The Forum's 100-strong membership comprises world class technical, business and government leaders from EMEA, Asia and the Americas who are passionate about creating a revolution in wireless communications based on reconfigurable radio. Forum members span commercial, defense and civil government organizations at all levels of the wireless value chain and include service providers, operators, manufacturers, developers, regulatory agencies, and academia." The Wireless Innovation forum is very active in the Defence domain even if a number of deliverables have been created for the Public Safety and Commercial domain as well.

In USA, the Federal Communication Commission (FCC) has adopted rule changes to address the certification of SDR equipment in [13], where SDR is considered a new class of equipment with streamlined equipment authorization. The purpose of the action is to modify certification rules to accommodate the flexibility offered by SDR. Specifically, FCC amended the equipment authorization rules to permit equipment manufacturers to make changes in the frequency, power and modulation parameters without the need to file a new equipment authorization application with the Commission. The action also permitted electronic labeling so that a third party may modify a radio's technical parameters without having to return it to the manufacturer for re-labeling. The certification rules were updated in [14] to further facilitate the development and deployment of SDR and CR. Specifically, the action eliminated the rule for a manufacturer to supply radio software to the Commission upon request because this may become an unnecessary barrier to entry.

The action also required the manufacturer to supply a high level operational description of the radio software that controls its RF characteristics for SDR certification. Security aspects were also addressed by requesting software controls to limit operation to authorized frequency bands.

In [14], FCC does not allow the Telecommunications Certification Bodies (TCBs) to certify SDR equipment. SDR certification is required to be carried out at FCC labs. The reason is because software defined radio is a new technology; TCBs will not be permitted to certify software defined radios until the Commission has more experience with them and can properly advise TCBs on how to apply the applicable rules.

The European context is more complex because of the geopolitical diversity and the presence of national certification centers and processes.

The European Software Radio Architecture (ESRA) is an on going standardization activity at European level. The goals are to ensure waveform portability and SDR reconfigurability. The ESRA standardization activity will be implemented through existing projects at European level like ESSOR [15], WINTSEC and its follow-up EULER, which is focused on the application of SDR for improved joint interoperability in Public Safety and defense.

Many organizations and industries in Europe are involved in this process. The (EDA) European Defence Agency is a main player in this process.

At the same time, ETSI (European Telecommunications Standards Institute) started a similar initiative to conduct feasibility studies for the standardization of a wider concept of SDR technology called RRS (Reconfigurable Radio Systems), which are defined as follows (from [16]):

"The group of technologies for Cognitive Radio and for Software Defined Radio are all technologies for Reconfigurable Radio Systems (RRS). Such systems exploit the capabilities of reconfigurable radio and networks and self-adaptation to a dynamically changing environment, with the aim to ensure end-to-end connectivity."

In comparison to EDA, which is focused on the military and public safety domain, the main target domains of ETSI RRS are the commercial domain and the public safety domain. ETSI RRS is composed by four working groups: WG1 for system design, WG2 for handset architecture, WG3 for functional architecture and WG4 for Public Safety domain.

From a standardization point of view, the ETSI RRS is performing work that is complementary to the IEEE SCC41 and IEEE 802 activities, with a focus on SDR standards beyond the IEEE scope, CR/SDR standards addressing the specific needs of the European Regulatory Framework and

CR/SDR TV White Space standards adapted to the digital TV signal characteristics in Europe.

Currently, there are no specific working items on the certification of SDR/CR equipment, but the TC maintains a close link with other ETSI TCs and organizations to ensure conformance of SDR/CR to the European regulatory framework. Technical standards on the SDR architecture are currently under definition.

The main challenge of SDR certification in Europe is currently the lack of technical standards for SDR/CR technology against which certification should be executed.

The WINTSEC project has laid the foundations of ESRA, which however has not yet reached the level of a standard but rather an architectural framework; the items defined in the ESRA document are not actual requirements but mere recommendations. The ongoing EULER project [17], which is expected to provide further ESRA recommendations extensions, will not also propose a standard.

However, certification is valid against a published standard; no certification can exist against an architectural framework. The consequence is that any certification guidelines described in the deliverables of the WINTSEC project are designed against a future, ESRA-derived standard, and that they are described as "compliance evaluation procedures" rather than "certification procedures".

The concept of compliance evaluation is significantly less rigid than the concept of certification for a number of reasons: a) evaluation is a much more informal, less authoritative procedure where the steps and requirements can be adapted to each specific test case; b) compliance evaluation can be performed on any relatively mature version of the product under test as it deals mostly with general properties of it, rather than specific details; c) the result of evaluation is a report elaborating on the estimate of each property's compliance to the guidelines; d) evaluation procedures are often related to new, rapidly evolving technological domains, where a standard and certification procedure would quickly become outdated or hinder development.

It is advisable that a set of guidelines/directives accompanied by compliance evaluation procedures evolves into a standard and certification procedure as the technological domain involved matures.

In Europe, certification of wireless equipment is driven by the Radio and Telecommunications Terminal Equipment Directive (R&TTE) that came into force in April 2000 in Europe. With the exception of a few categories of equipment, the Directive covers all equipment, which uses the radio frequency spectrum. A basic requirement is that radio equipment shall be so constructed to effectively use the spectrum allocated to terrestrial/space radio communication and orbital resources so as to avoid harmful interference. The adaptation of the R&TTE directive for SDR technology has been investigated by the Telecommunications Conformity Assessment and Market Surveillance Committee (TCAM), which is the standing Committee assisting the European Commission in the management of the R&TTE Directive 99/5/EC. In TCAM, the specific sub-group TGS (TCAM Group on SDR) was created to investigate SDR regulation with respect to the R&TTE Directive. Based on a TGS report provided to TCAM in 2006 ("Conclusions concerning the regulatory aspects of SDR with respect to the R&TTE Directive"), and on discussions in TCAM, the European Commission draw some conclusions to particular discussion points, but the discussion was not finalized.

Two deployment models for SDR technology are considered:

- Vertical mode, where the terminal reconfiguration can only be done (and authorized) through the equipment manufacturer (who also takes the responsibility).
- Horizontal model, where the reconfigurations can be authorized by different actors. The software only needs a declaration of standard compliance. This responsibility can be taken by different actors.

The following conclusions were presented:

- For downloaded SW, a digital marking (e.g., CE marking) is recommended.
- It is recommended to maintain, in the SDR devices, a history of software changes.
- SDR equipment would be considered as a "relevant component", in the meaning of Article 2 of the R&TTE Directive.
- Harmonized standards covering SDR devices should contain countermeasures against illegal programming and hacks for equipment, which are at risk.

Future versions of the R&TTE Directive may incorporate additional elements for SDR certification.

In summary, we can identify the following challenges for SDR certification in Europe:

- SDR technical standards should be defined for all the relevant domains: military/public safety and commercial.
- Identify who should have the responsibility of the final product or its components including software waveforms, SDR HW platform and software framework (e.g., SCA). This is especially important for a horizontal market.
- The European SDR certification process should address the geopolitical diversity of Europe and the existing national organizations and certification centers.
- Ensure that SDR technology validates harmonized radio-spectrum regulations at European level and non-harmonized regulations at national level.
- Ensure that all the certified waveforms and SDR platforms are managed in a controlled environment and accessible to end-users across Europe.

III. Proposal Of A SDR Certification Framework

The purpose of this section is to describe a SDR certification framework, which is able to address the challenges, describes in the previous section.

The certification framework is based on the following elements:

- Reference implementation, which complements existing or future standards on SDR. Reference implementations are useful to resolve ambiguities in the standards definition.
- Procedures and tools to certify API compliance
- Use of Reference platforms against which waveforms should be certified.
- A European certification network to address the geopolitical diversity of Europe.
- A repository of waveform libraries, which can be accessed by end-users across Europe.
- A waveform usage and issue tracking to manage issues and changes in the versions of the waveforms.

The SDR certification framework addresses the horizontal model, which is the most complex of the SDR certification and deployment models.

The following stakeholders are identified:

- SDR HW platform manufacturers, which are responsible for designing and deploy the SDR HW platforms
- The SW waveforms designers, which are responsible for the creation of SW waveforms in accord to specific standards and specifications.
- The telecom provider, which provides the network deploying SDR technology.
- The user/subscriber of the SDR platform and the network.

- The administrative organizations, which include the European and national spectrum regulators and the authorities, which manage the use (and certification) of SDR technology in the market.
- The certification authorities, which may be industry or government representatives.

A. *Reference Implementation*

Naturally, a large effort is made during the design of a standard to be as concise, consistent and complete as possible. However, it is realistically *inevitable* that any standard contains ambiguities, gaps or sometimes even contradictions in its definition. This runs contrary to the goal of standard compliance, which is seamless interoperability between components or systems.

A trend that is becoming more and more prevalent is for any standard to be complemented by a reference implementation. This is an open, free and complete software implementation of the standard, usually defined by a neutral, impartial, independent and trusted entity. The goal of such an activity is to clarify the standard, while at the same time encouraging wide adoption.

Any ambiguities in the wording of the standard should be easily resolvable by consulting the source code of the reference implementation. Furthermore, any contradictions inside the standard definition should be discovered during the development of the reference implementation, and the standard drafting body (or consortium) should be notified, in order to rectify them. It is therefore evident that two-way flow of information between the standard drafting body and the developers of the reference implementation is necessary to improve the quality of the standard.

The reference implementation should be thoroughly documented, as the goal is clarity. A high-level language should be preferred, since code readability should be preferred over efficiency in a reference implementation. Finally, the code should be extensively cross-referenced to the articles and clauses of the related standard, in order to improve the tracking of the design choices in the reference implementation.

B. *Certifying API Compliance*

The outcome of a software standard is often a set of Application Programming Interfaces (APIs), which allow other programs or modules to interface with and exploit the capabilities of software components. Therefore, an important activity of the certification process for standard compliance is to check compliance to the resulting API.

Certification of a component's compliance to a given API is usually done by executing a software test tool (or set of tools) that thoroughly checks the existence of all the functions and data structures defined in the API in the component under test and their robustness (stress testing). For example a method might be called with a predefined set of arguments, and the result would be compared to the expected result. This is commonly called Unit Testing. Part of the stress testing process might be calling methods with erroneous/invalid input parameters; in this case, an error should be returned by method and the software executable under test should not enter in an undefined state. For example, the software executable should not crash or hang.

Unit testing has a set of limitations: it can only follow a limited number of execution paths, and therefore it can only test for the existence of a limited number of errors. In other words, unit testing cannot guarantee the absence of errors.

Finally, while unit testing can confirm the existence and correct operation (under normal conditions and under stress) of all the methods and objects in an API, it cannot test for the existence of additional methods and/or objects (extensibility).

Development tools could also be used for testing and validation of the waveform and SDR framework (e.g., SCA) code. In the early days of computer programming, source code was written in a single long file using a plain text editor. The target had single processor architecture. Today, especially in the SDR context, the common practice is to create first a platform-independent model of a component, then a platform-specific model, and then generate code for multiple architectures (e.g., GPP, DSP and FPGA).

Therefore, complex and powerful Integrated Development Environments (IDEs) are used throughout the industry. These IDEs provide a long series of additional features to the developer, such as syntax highlighting, auto completion, build automation, debugging, version control, built-in documentation, configuration management and others.

Often these tools include (either built-in, or in the form of plug-ins) compliance testing functionalities for a specific standard. This is highly beneficial for the process of pre-certification, as it allows developers to test their code for standard compliance parallel to their coding efforts (two of the four basic Extreme Programming activities), rather than test for compliance towards the end of the development process, when it actually might be too late. The reference implementation might be instrumental in this compliance testing process.

Example of Development and Testing Tools are the CRC's SCA Architect and Prismtech's Spectra CX, which are both based on the Eclipse IDE.

C. *Reference Platforms*

While part of the certification testing of a waveform's components might occur on the source code or the configuration/interface files, some of the tests will inevitably need to be run on the full, ported waveform, which is downloaded and activated on the SDR platform.

While it would be possible to select a high-quality SDR platform (i.e., the reference platform), against which all waveforms should be run for certification testing, several problems arise from this approach:

1. Such a choice would give the manufacturer of the SDR platform an undeniable and unfair advantage over their competitors, as they would be able to claim to be the "preferred platform provider". Furthermore, such a choice would tie the European

SDR Certification community to a single vendor, denying all the benefits of market competition like costs reduction, supply chain diversification, etc).

2. The standard must be meticulously implemented in the waveform and reference platform. Otherwise, a single reference platform would create a de facto standard, which might slightly differ from the paper standard; waveform developers would be forced to comply with this de facto standard to pass certification.

As a solution to these problems, it is suggested to adopt multiple reference platforms for certification testing. A waveform under test would be ported, loaded and run on multiple platforms. A certification failure on a single platform would require further examination, but might hint to an incompatibility of the underlying platform. Instead, certification failure on two or more platforms would still require further examination, but it would indicate that most probably the error lies in the waveform under test.

The relationship among the various certification activities is described in Figure 1.

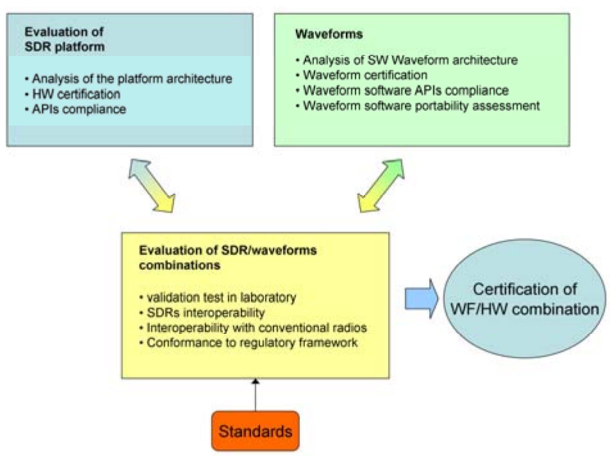

Figure 1 The relationships among different certification areas.

In the first phase, the SDR platforms and the waveforms are separately tested and certified for compliance to the standards. If these steps are successful, the next phase is the certification of the combinations of SDR platforms (i.e., HW) and Waveforms (i.e., SW).

An important certification activity is the conformance to the regulatory framework (e.g., the spectrum regulations) for the areas where the SDR Platforms and Waveforms are supposed to operate. For example, the SDR should not generate harmful interference to licensed users.

The validation activity should also include the case of roaming where a SDR device is used in different contexts with different national spectrum regulations.

At the end of the certification process, the certification body should release a compliance certificate, which includes the spectrum regulations considered in the testing activity.

D. SDR Certification Network

The technical requirements for the certification of SDR and its components must be mapped to a certification procedure. SDR certification tools need to be developed, either from scratch, or (more likely) building upon existing certification tools (e.g., the xUnit test framework). Then these procedures can be executed (using test tools) on a network of certification centers throughout Europe.

Some characteristics of this network:

- A centralized certification authority would not execute actual certification of products; instead it would prepare, monitor and accredit the certification centers, making sure that they are compliant to the shared certification procedures and tools.
- Location transparency of the certification process is a necessary requirement. It means that it shouldn't be easier to pass certification at one centre rather than another.
- Certification laboratories might be included in the process; these would be industrial champions or centres of excellence in a specific technological area (e.g., FPGAs), and would perform partial certification in that area for components developed by themselves or others. This is an extension of the concept of self certification.
- Redundancy should be considered to address occasionally increasing certification workload, or problems in the certification process.

A description of the structure of the European SDR certification network is provided in Figure 2, where Waveform and SDR platform certification centers are dependent on the national certification centre, which are connected to the centralized certification and accreditation authority. Note that centre for the validation against spectrum regulations can be affiliated both to a national centre and the centralized centre to include testing of roaming functionality among different nations.

The optimum number of certification centers is difficult to decide: some European larger countries might choose to create more than one certification centre, while smaller countries may decide to share the cost with other countries, or depend on larger countries for their certification needs.

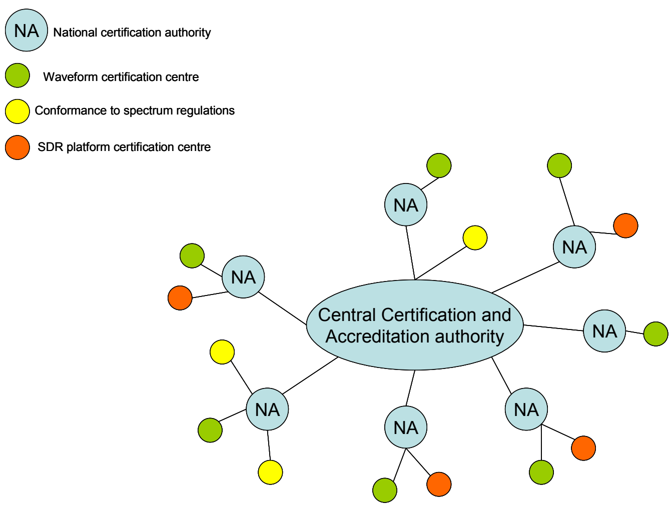

Figure 2 The structure of a potential European SDR certification network

In addition to the benefits of redundancy and national independence achieved by having a network of certification centers instead of a single one, the network would mitigate the risk of a slightly different, de facto standard created by a single certification centre as in the case of multiple reference platforms.

Finally, it would be mutually beneficial to maintain a close relationship with the US SDR certification centers (e.g., JTeL), to exchange know-how and possibly share procedures and tools.

E. *Waveform Libraries*

The creation of a central repository to maintain and distribute software modules is a common practice today. This approach provides the following advantages:

- A central repository provides more control for the storage and maintenance of certified software modules.
- The customers have easier access to a central repository.
- It is easier to implement automatic download and updates for new versions/features.
- It is easier to apply specific signatures on the certified software modules.

A similar approach is proposed to store the certified SDR Waveforms: a common, centralized repository (called “Waveform Libraries”) of all the waveforms that have passed certification against the standards. This would facilitate over-the-air (OTA) downloads of complete waveforms as well as upgrades of waveforms and components. At the same time this repository would be a valuable tool during the certification process, by storing the results of the tests and keeping a history of past certifications.

Because of the presence of various administration authorities in Europe, it is suggested to have a distributed, redundant architecture for this repository, possibly with one instance per certification centre and one per national authority; limited, stripped-down versions of the repository might even be included in the local, encrypted storage of the SDR base stations and terminals in the field.

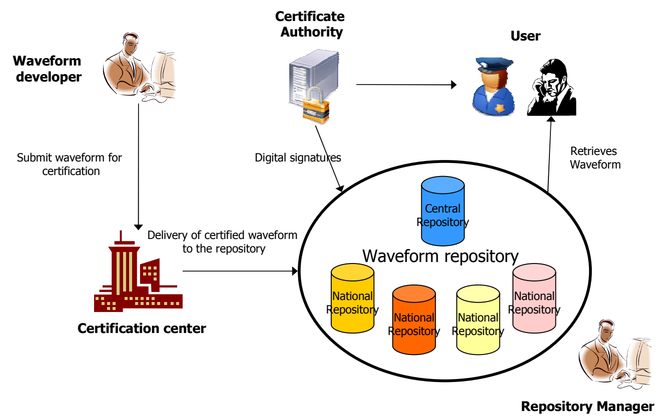

Figure 3 Waveform Repositories

Such a repository could include source code, binary files of the waveforms, or both. Additionally, it would certainly include configuration files, model/interface files (UML, IDL, etc), other meta-data related to deployment and use (such as performance requirements), and documentation files both for the porting/certification process and for the deployment/usage.

Some additional tags should accompany each waveform in the repository: information about certification status, the version of the standard with which the waveform complies, the communications protocol implemented, the license scheme, the owner of the waveform, etc. It will also include the information on the SDR platforms against which the waveform has been certified.

The structure of the waveform libraries is described in Figure 3, where the main stakeholders are present. The waveform developer submits the waveform for certification to the certification centre. After the certification, the waveform is stored in the national and centralized repository together with the information described above. The certificate authority can add digital signatures to the waveform to guarantee the security for the software download. Finally, the customer can collect or download the waveforms.

F. *Waveform Usage & Issue Tracking*

Alongside the waveform libraries discussed above, two additional tools are needed in the European SDR ecosystem to keep track of waveform usage and reported issues.

One tool is used to track waveform usage in customers. Tracking waveform usage would be useful to understand the needs of the end-users/customers, to introduce upgrades (using a push-mode, rather than a pull-mode in order to deploy upgrades to all the users of a specific waveform or component), and possibly also for licensing and fees collection. A waveform usage directory (WUD) could be used to identify gaps in the SDR ecosystem and it would allow the central authorities to know which customers are using the waveforms. This tool can also be used to improve the efficiency of technical support and customization, but identifying which categories of customers are using specific waveforms.

The other tool is a centralized issue tracking system (ITS) that is integrated with the Waveform Libraries and the WUD. Its objective is to report and track any issue related to the malfunction of certified SDR platforms and waveforms or a request for an enhancement. The centralized ITS will store the list of all the available waveforms and it will allow customers to report issues.

The ITS will be based on a classical issues tracking flow. Once a new issue is reported by a customer, the issue tracking process will verify whether the issue reported is a known issue (i.e., a duplicate of another issue already registered in the ITS), if it is an enhancement request, if it is not really a waveform issue, but a deployment/configuration issue on the side of the end-user, or if it actually is a new issue that needs to have the developer's attention. When an issue is resolved by the developer, the ITS combined with the WUD would allow for efficient distribution of the update to all the users of the affected waveform or component.

Finally, the centralized Issue Tracking System would allow the involved partners and supervising authorities to collect statistics about the quality of the waveforms and waveform components (thus measuring the performance of waveform developers), as well as the performance of the support organizations.

IV. Performance Benchmarking Certification

SDRs are generally considered soft real-time systems, in the sense that signal processing has to keep up with the data rate of the communications system. In other words, the result of a calculation must not only be accurate, but it must also be completed by a certain deadline, otherwise it will not validate the operational requirements.

Each SDR waveform has specific performance requirements that need to be fulfilled, in order for it to run in real-time. These requirements might include definite processing speed from a processing core, a certain bandwidth or latency between processing cores, or the availability of certain components (e.g., an OCXO, or an RF front-end with a certain frequency range).

A. Performance Metrics

In order to compare the performance available on the platform with the performance required by the waveform, it is necessary to have a common way of describing and measuring these performance requirements and capabilities.

This task is more or less complex if an SDR Set operates in single-mode than when it operates in multi-mode. With single-mode we mean that a single waveform will execute on the platform at any single moment, while with multi-mode we mean that multiple waveforms will execute on the platform at any single moment, with voice, video and data bridges between them. A terminal will probably operate in single mode most of the time, while a base-station is most likely to operate in multi-mode.

In multi-mode, we should differentiate between the nominal (zero-load) performance that the platform can provide, and the actually available performance when one or more waveforms are already running on the platform.

B. Performance Benchmarking

Measuring the performance capacities of an SDR platform and the performance requirements of a SDR waveform is a valuable activity both during design phase and deployment phase.

Specifically, performance benchmarking during the design phase of a platform or of a waveform can allow developers to identify components that are performance hogs and focus their optimization efforts on these bottlenecks. On the other hand, performance benchmarking is essential when making purchasing or waveform porting decisions: it enables authorities to determine the feasibility of a waveform porting onto a platform by providing assurance that the waveform performance requirements will be satisfied by the platform hardware and software resources. Furthermore, once porting feasibility has been guaranteed, benchmarking can drive the adaptation effort of the porting.

Therefore the benchmarking has to start early in the design or porting process in order to limit the cost and time of the porting effort.

C. Processing Cores Benchmarking

CPU benchmarking might be the most widely studied and applied type of benchmarking in the computer industry. A wide selection of both open-source and proprietary solutions are available for CPU benchmarking; some of these tools are based on integer or floating point arithmetic, others on linear algebra operations, and others still on compression or audio/video encoding algorithms.

Here we mention only three of the most widely accepted CPU benchmarks: EEMBC's Coremark, HPL (High Performance Linpack) and Livermore loops. With minor modifications these tools could be ported to the SDR domain and be used in benchmarking GPPs/FPGAs and DSPs in SDR platforms.

Each SDR HW component may be used for specific tasks. For example, DSPs concentrate mainly on FIR/IIR filters, FFT calculations and codec implementations, so naturally these are the kinds of operations benchmarked. An example of DSP benchmarking is BDTi's DSP Kernel Benchmarks: a proprietary solution that executes 12 different types of benchmarks on each processor.

However, many of the graphics cards used for gaming PCs can be considered DSPs. In fact, several efforts are currently under way to exploit the DSP potential of commercial graphics processing units (GPUs) using either nVidia's CUDA or Apple's OpenCL for signal processing. Furthermore, General Purpose Graphics Processing Unit (GPGPUs) such as the Cell processor (found in Sony's Playstation 3) or Intel's Larrabee show promising potential for mixed generic and signal processing applications, which makes them a good fit for SDR applications. See [18] for a description of the use of GPGPU to realize SDRs on desktop computers with distributed resources. In both the above cases, a multitude of benchmarking tools already exists.

D. Benchmarking the entire SDR platform

In addition to the procedures discussed above, which target specific components of an SDR platform, it is important to complement them with benchmarks that test the SDR platform as a whole; these types of tests often reveal bottlenecks that might go undetected by examining individual components separately.

The MPrime application is one such test. MPrime was originally developed to search for prime Mersenne numbers; however, due to the very intense performance requirements it imposes on the underlying platform, it is often used to stress-test computing systems for stability. Other such stress-testing tools are the FurMark (a closed-source, Windows-only fur-rendering performance and stability test for the GPU), or distributed computing clients such as the University of Berkeley's BOINC.

Another tool that could be used for benchmarking the SDR platform as a whole is the Phoronix suite (see Figure 4), probably the most widely used open-source test suite for Linux operating systems. It includes tests for the processor, memory, disk, and graphics and also for the system as a whole.

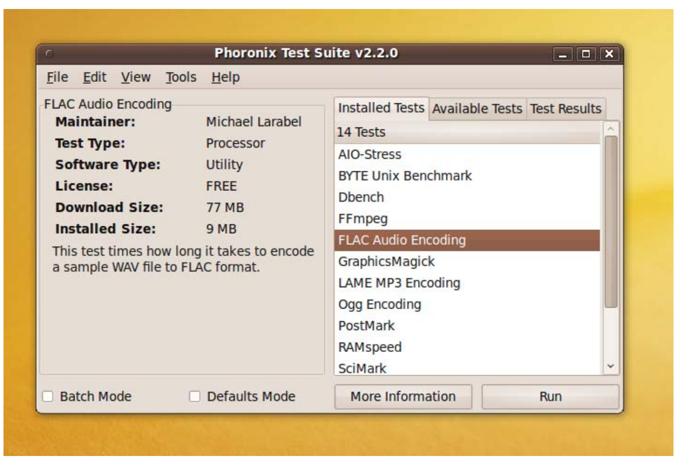

Figure 4 Phoronix Test Suite v2.2.0.

E. Power consumption benchmarking

Another architectural area, which requires performance benchmarking, is power consumption/power efficiency. This is an issue that is increasingly seeing the attention of both industry and academia, and a rather problematic area for the SDR domain (especially for handheld/portable radios) due to lower power efficiency of the more generic hardware (both processing and RF) used in SDR compared to the specialized hardware used in traditional legacy communications systems.

An example of benchmark tool for power consumption is PowerTop, an open-source tool released by Intel in 2007 as part of the LessWatts effort. PowerTop measures and tries to estimate the power consumption of software processes and device drivers, thereby identifying the culprits and guiding the effort of developers to minimize power consumption. This tool was successfully used in improving the power consumption of the Firefox browser and of several device drivers and kernel subsystems.

F. Benchmarking of SDR waveforms

While measuring the performance of a SDR platform is useful in the design, purchasing and waveform porting phases; it is instrumental to measure also the performance of an SDR waveform before porting or deployment.

OProfile is a system-wide profiler for Linux systems, which allows developers to receive real-time statistics about the resource usage of all a waveform's components with low overhead (usually less than 1%), in addition to several post-processing tools for analyzing these statistics. OProfile uses hooks in the Linux kernel to raise interrupts, and can be used both on x86 and on ARM processors.

OProfile is sponsored by some major companies such as IBM and RedHat. An OProfile plug-in exists for the Eclipse development framework, on which both Prismtech's and Zeligsoft's SDR development environments are based.

G. Benchmark cheating

Several incidents have been reported in recent years of cheating in CPU benchmarks, 3D accelerator benchmarks, Java VM benchmarks and others. This is commonly called as “benchmark cheating”. It is therefore important that statistically rigorous techniques are used when evaluating the performance of SDR components and systems in order to avoid deceptive advertising and other irregularities:

- Run not one, but multiple different benchmark tools on the target in order to avoid “on-demand” benchmarks, i.e., benchmarks that favor one system vendor over the others.
- Run each of the benchmark tools on the device-under-test (DUT) a sufficiently large number of times, and clearly describe the statistical analysis on the vector of the results that led to the final benchmark output, so as to avoid e.g., reporting of only the best result obtained or arbitrarily discarding unfavorable results.

Finally, [19] describe tools from theoretical computer science including randomization, one-way functions, and trapdoor functions, which are used to improve the robustness of benchmarks against cheating.

V. SECURITY CERTIFICATION

As described in the previous sections, software portability should include security mechanisms, which guarantees the authenticity of the waveform and the trust of the SDR platform and waveforms.

The certification process is based on certification criteria, which are defined on the basis of regulations, standards and industry specifications. There are usually two certification processes: one process to certify the SDR platform, which includes the HW platform, RTOS and software framework and the second process for the waveform certification. Additionally, a certification process should be established for the security requirements. Security certification is an essential protection against security threats like download of malicious software, masquerading of a SDR node and denial of service (DoS). The security certification process for SDR can be based on similar processes already defined in the computing domain like the Common Criteria [20]. Among other things, Common Criteria are used to develop Protection Profiles, which identify the security requirements, and Assurance Levels, which describe the rigor of testing and evaluation. The combination of Protection Profiles and Assurance Levels results in a Security Target against which the certification process can evaluate a product. This model is appropriate for the future use of SDR in different markets: military, public safety and commercial with different security requirements and equipment costs. For each domain, we can define different types of protection profiles and security targets.

In comparison to conventional wireless equipment, the security certification process is particularly complex for SDR equipment because of the complexity of the technology and because various stakeholders could be involved in the certification process. A description of the challenges in the certification of non-functional requirements like security is provided in [9], which notes that certifications for security requirements are intrinsically different and more complex from those covering functional or process requirements, as they need to model the user as malicious for all the potential security threats and this increases the number of test cases.

An additional level of complexity is the presence of supplementary stakeholders like the certificate authority, which should be part of the certification process. The number and the role of the stakeholders depend on the related domain: military, public safety and commercial domain. In the military and public safety domains there are usually well defined security certification processes for conventional equipment, which can be adapted to SDR technology.

VI. CONCLUSIONS AND FUTURE WORK

Standardization is still an ongoing process, with multiple stakeholders involved. The goal of a European SDR standard is to facilitate waveform portability and system interoperability. To ensure these benefits, a network of certification centres accompanied by the relevant certification procedures and tools needs to be developed. These concepts were studied in the context of a European SDR Architectural Framework inside the WINTSEC project. The importance of performance metrics was described, as they're particularly important in order to validate the operational requirements in the public safety domain. Possible pitfalls were identified, including sensitive issues, either political or commercial. The need for Waveform Libraries, as well as a Waveform Usage & Issue Tracking directory were explained. Performance and Security aspects are particularly important in SDR technologies This paper described metrics, processes and tools for Performance benchmarking with special focus on mitigating the risk of performance cheating. This paper also described SDR security certification and the relationship to Common Criteria.

Future work will focus on the definition of a comprehensive framework for security certification of SDR equipment. The framework will include identification of the main stakeholders and related roles, certification processes and the link to the standardization activity.

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