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Contents

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Foreword

This Technical Report (TR) has been produced by ETSI Technical Committee Reconfigurable Radio Systems (RRS).

Introduction

The present document provides a feasibility study on creating a reference architecture for such mobile devices which are capable to use technological elements known as Software Defined Radio. Such mobile devices will operate as functional elements in reconfigurable radio systems by using multiple different radio standards simultaneously.

As a feasibility study the present document provides basis for decision making at ETSI Board level on standardization of some or all topics of the SDR Reference Architecture for Mobile Device.

1 Scope

The present document describes the reference architecture for SDR equipped mobile devices, which allows them to operate as part of reconfigurable radio systems. The reference architecture is outlined in the present document to the extent which is necessary to identify architectural elements (components and interfaces) as candidates for further standardization. As a basis for the reference architecture common requirements for such a SDR mobile device are also in the scope of the present document. Since the feasibility of standardization of architectural elements for SDR mobile devices also depends on already standardized or ongoing activities on such architectural elements the present document also provides a survey on SDR standardization in other SDOs.

2 References

References are either specific (identified by date of publication and/or edition number or version number) or non-specific.

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2.1 Normative references

The following referenced documents are indispensable for the application of the present document. For dated references, only the cited version applies. For non-specific references, the latest version of the referenced document (including any amendments) applies.

Not applicable.

2.2 Informative references

The following referenced documents are not essential to the use of the present document but they assist the user with regard to a particular subject area**.** For non-specific references, the latest version of the referenced document (including any amendments) applies.

[i.1] OMG sbc/07-06-07: "Software Radio Specification Overview".

[i.2] IEEE P1900.4: "Draft Standard for Architectural building blocks enabling network-device distributed decision making for optimized radio resource usage in heterogeneous wireless access networks".

[i.3] IEEE P802.22: "Draft Standard for White Spaces".

[i.4] IEEE P802.21: "Draft Standard for Local and Metropolitan Area Networks: Media Independent Handover Services".

[i.5] The MIPI Alliance.

NOTE: Web page at http://www.mipi.org/wgoverview.shtml.

[i.6] ETSI TR 125 913: "Universal Mobile Telecommunications System (UMTS); LTE; Requirements for Evolved UTRA (E-UTRA) and Evolved UTRAN (E-UTRAN) (3GPP TR 25.913 version 8.0.0 Release 8)".

[i.7] 3GPP TR 36.913: "Technical Specification Group Radio Access Network; Requirements for Further Advancements for E-UTRA (LTE-Advanced) (Release 8)".

[i.8] RP-080758 Work Item: "Description on RF requirements for Multicarrier and Multi-RAT BS", TSG-RAN Meeting #41, Kobe, Japan, 9 - 12 September 2008.

[i.9] "The Khronos Group OpenMAX Integration, Development and Application Layer Programming Interface Specifications, 2008".

3 Definitions and abbreviations

3.1 Definitions

For the purposes of the present document, the following terms and definitions apply:

mobile device: personal communication device (e.g. mobile phone, PDA, laptop PC etc) capable of communicating either locally (e.g. Bluetooth), through a network (e.g. GSM) or both by using one or more radio technologies

radio application: software application executing in a software defined multiradio equipment

NOTE: Radio application is typically designed to use certain radio frequency band(s) and it includes agreed schemes for multiple access, modulation, channel and data coding as well as control protocols for all radio layers needed to maintain user data links between adjacent radio equipments, which run the same radio application

radio equipment: equipment using radio technology

radio system: system, which consists of a number of radio equipments using at least one common radio technology

radio technology: technology for wireless transmission and/or reception of electromagnetic radiation for information transfer

software defined radio: radio in which the RF operating parameters including, but not limited to, frequency range, modulation type, or output power can be set or altered by software, and/or the technique by which this is achieved

NOTE 1: Excludes changes to operating parameters which occur during the normal pre-installed and predetermined operation of a radio according to a system specification or standard.

NOTE 2: SDR is an implementation technique applicable to many radio technologies and standards.

NOTE 3: SDR techniques are applicable to both transmitters and receivers.

software defined multiradio: device or technology where multiple radio technologies can coexist and share their wireless transmission and/or reception capabilities, including but not limited to regulated parameters, by operating them under a common software system

NOTE 1: Examples of the regulated parameters are frequency range, modulation type, and output power.

NOTE 2: Common software system represents radio operating system functions.

NOTE 3: This definition does not restrict the way software is used to set and/or change the parameters. In one example, this can be done by the algorithm of the already running software. In another example, software downloading may be required.

software defined radio equipment: radio equipment supporting SDR technology

3.2 Abbreviations

For the purposes of the present document, the following abbreviations apply:

API	Application Programming Interface
ASIC	Application Specific Integrated Circuit
ASIP	Application Specific Instruction Processor
BB	BaseBand
BBIC	BB Integrated Circuit
CDR	Computer Defined Radio
CM	Configuration Manager
CMOS	Complementary Metal-Oxide Semiconductor
CORBA	Common Object Requesting Broker Architecture
CR	Cognitive Radio
DSP	Digital Signal Processor
EMR	Electro-Magnetic Radiation
FC	Flow Controller
GGSN	Gateway GPRS Support Node
GPRS	General Packet Radio System
HW	HardWare
IP	Internet Protocol

NOTE: As in TCP/IP.

IP	Intellectual Property

NOTE: As in semiconductor IP.

JTRS	Joint Tactical Radio System
LTE	Long Term Evolution
MDA	Model Driven Architecture
MIH	Media Independent Handover
MIHF	Media Independent Handover Function
MIPI	Mobile Industry Processor Interface
MRC	MultiRadio Controller
MURI	MUltiRadio access Interface
OFDM	Orthogonal Frequency Division Multiplexing
OMD	Object Management group
PDA	Personal Digital Assistant
PIM	Platform Independent Model
PMSE	Program Making and Special Events
PSM	Platform Specific Model
RCM	Radio Connection Manager
RF	Radio Frequency
RFIC	RF integrated circuit
RM	Resource Manager
RPI	Radio Programming Interface
RRFI	Reconfigurable RF Interface
RRS	Reconfigurable Radio System
SCA	Software Communications Architecture
SDF	Synchronized Data Flow
SDO	Standards Development Organization
SDR	Software Defined Radio
SIMD	Single Instruction Multiple Data
TCP	Transport Control Protocol
URA	Unified Radio Application
URAI	Unified Radio Application Interface
WCDMA	Wideband Code Division Multiple Access
WLAN	Wireless Local Area Network

4 Requirements on SDR equipment for mobile device

This clause collects the requirements on SDR equipments for mobile devices as presented by a number of stakeholders, including but not limited to radio chipset vendors, mobile device manufacturers and network operators. These requirements have been taken into account in the reference architecture described in the present document.

Requirements discussed below are categorized into 5 groups:

1) General architectural requirements.

2) Capability requirements.

3) Operational requirements.

4) Interface requirements.

5) Other requirements.

The potential business relationships between different mobile device SDR stakeholders are illustrated in figure 1.

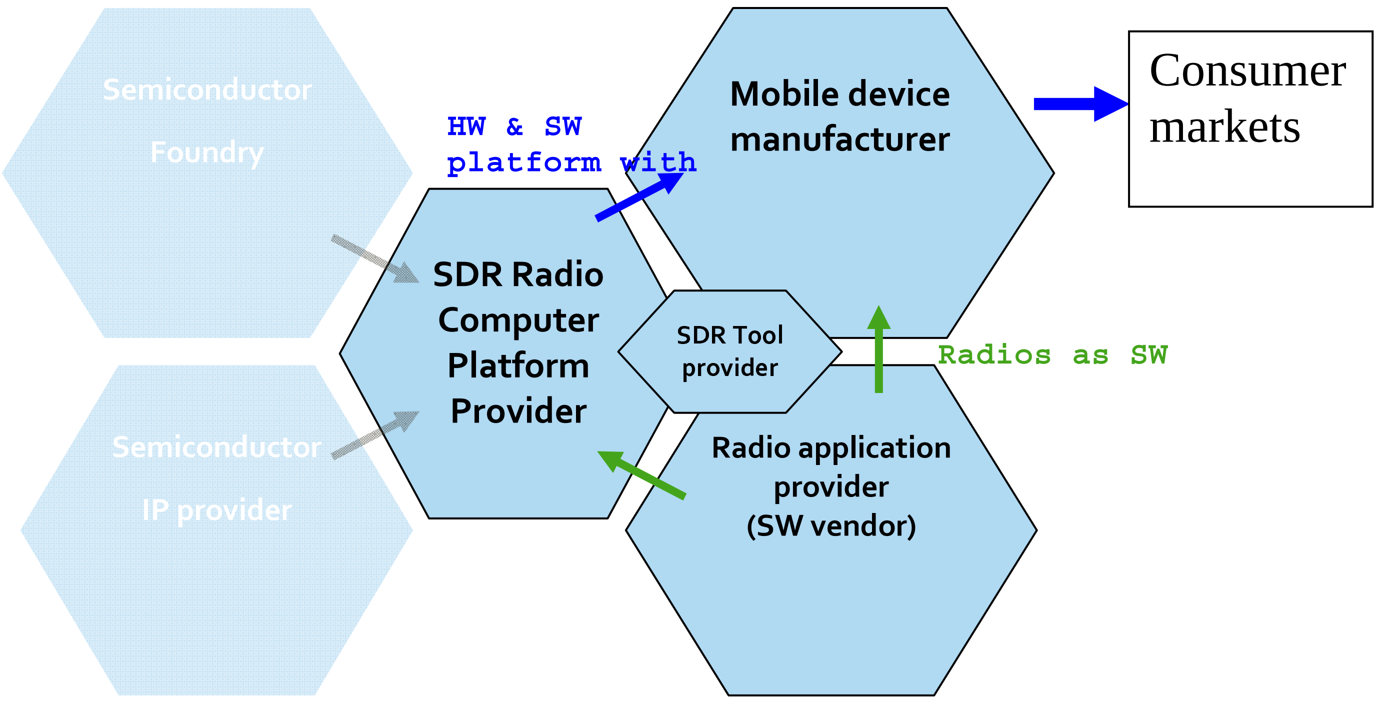

Figure 1: Future SDR value network

With the introduction of the SDR technology the radio chipset vendors will become responsible for integration of complete radio computers. They may use separate manufacturing companies (semiconductor foundries) and integrate also IP blocks from other semiconductor vendors e.g. outer modem HW accelerators. Such radio computers, which may include some built-in radio applications, are provided as radio platforms to mobile device manufacturers. Mobile device manufacturers develop their consumer products, like mobile phones, multimedia computers and PDA devices, which use the radio computers as subsystems for communications purposes. Mobile device manufacturer may also choose to implement itself some radio applications into the radio computer platform. While radios continue to be used for multiple different purposes and new radio technologies continue to emerge development of radio applications as software entities may become a business of itself. Such radio application providers may develop and market their radio applications to multiple radio computer vendors and mobile device manufacturers. This kind of value network may also allow some software companies to become radio software tool vendors having multiple radio developer companies as their customers.

From the regulatory point of view the mobile device manufacturer remains responsible of all radio equipment functionality embedded into its consumer market product.

4.1 Architecture requirements

The SDR reference architecture for mobile devices needs to cover radio functionalities from antenna interface up to the networking interface.

The SDR reference architecture needs to follow modern design principles, such as model driven and component-based design practices in order to end up into a modular architecture, which can support integration of radio application software from different providers. Also portability of radio applications from one SDR platform to another is to be seen as important design criteria.

The SDR platform is designed as multiradio computer platform, which may be composed of one or more general purpose control processor(s) and of one or more specialized co-processors (e.g. digital signal processor clusters, vector processors etc). This kind of heterogeneous multi-processor architecture operates under tight real-time constraints (in µsec range) and is bound by a tight power budget. Dynamic reconfiguration of the hardware platform also needs to be supported by the architecture. How to provide secure execution environment for all radio applications running on a common radio computer platform is also an important design criteria.

4.2 Operational requirements

The SDR radio applications will operate on multiple frequency bands (e.g. from 400 MHz to 10 GHz) and use multiple bandwidths (e.g. from 200 KHz to 500 MHz). They also cover multiple radio technologies, including existing cellular access and non-cellular radio technologies as well as new ones which are likely to emerge with the introduction of cognitive radio systems. The radio applications in the SDR equipments will continue to conform to their specific radio interface specifications and standards.

Both connectivity radios (for user data transfer) and other types of radios, such as digital media broadcasting, geopositioning and wireless sensing radios need to be supported by the common SDR reference architecture.

SDR equipment may execute radios on both licensed and unlicensed frequency bands.

4.3 Capability requirements

Multiradio configuration capability: SDR equipment in mobile device is expected to install, load and activate a radio application while running a set of radio systems already. Correspondingly it allows active radio systems to become deactivated, unloaded and uninstalled.

Multiradio operation capability: SDR equipment in mobile device is expected to execute number of radio systems simultaneously by taking into account temporal coexistence rules designed for their common operation to mitigate inter-radio interference.

Multiradio resource sharing capability: SDR equipment in mobile device is expected to execute number of radio systems simultaneously by sharing computation, memory, communications and RF circuitry resources available on the radio computer platform by using appropriate resource allocation, binding and scheduling mechanisms.

4.4 Interface requirements

The interfaces in the SDR reference architecture are defined in order to support the requirements defined in clauses 4.1 to 4.3. Especially those interfaces which can enable business boundaries between different stakeholders need to be identified in the reference architecture.

First of all the SDR equipment will provide a service interface to its user entities representing the network protocol stack (e.g. TCP/IP) and other user domain entities in the mobile device. Such a **Multiradio access interface** provides a uniform way to access all radio applications in the SDR equipment.

Another important system-wide interface needs to be specified at the boundary between the common radio computer platform and the specific radio applications. This **Unified radio application interface** is used to adapt and align all kinds of radio applications under the common reconfiguration, multiradio execution and resource sharing framework of the SDR reference architecture.

One of the key objectives of the SDR reference architecture is to allow uniform production of radio applications as software entities. This can be achieved by introducing as part of the architecture a **Radio programming interface**. This is both a radio software development time concept as well as a run-time interface between radio software entities and the radio computer platform. This interface needs to include a uniform radio programming model that combines required run-time dynamism with real-time guarantees and efficiency. The programming model needs to be platform neutral and allow multiple radio compilers to be used for generating run-time radio packages for different platforms from the same source program. Additional aspects to be taken into account in the radio programming interface are virtualization of hardware peripherals of the radio computer such as reconfigurable RF devices.

Due to the foundational role of RF circuitry in any radio equipment the SDR reference architecture may benefit a lot from the ongoing technical evolution in the RF circuit design area. We anticipate the emergence of a more generic **reconfigurable RF interface**, which will support multiple radio applications and may even support sharing of the same circuitry among simultaneously active radio applications with similar enough RF properties.

4.5 Other requirements

Besides the architectural and technological requirements discussed above the SDR equipments will bring new kinds of usage scenarios, which are likely to require additional mechanisms to become accepted in mass markets. The conformance of all radios and their combinations on the same platform will still fulfil the EMR and other product safety regulations. The conformance testing of SDR equipments may require additional measures, which need to be investigated also.

The introduction of computerized SDR equipments is bringing programmability of mobile devices into a new level, which needs to be accompanied with appropriate mechanisms to ensure authentication and secure operation of installed radio applications on every SDR platform.

5 SDR reference architecture for mobile device

5.1 Operating environment

SDR equipments will operate in the same kinds of networking environments as today's mobile phones, PDAs and laptops. Both licensed and unlicensed frequency bands will remain in use. SDR equipments will be used in user terminals in operators' networks as well as peer equipments in short range, personal and ad hoc networks. Radio and TV broadcasting stations and geopositioning satellites will also be used as distant communication peers of SDR equipments.

Besides existing radio technologies new radio technologies and frequency bands will become available to SDR equipments. Therefore the design of SDR equipment architecture will be prepared for new frequency bands and radio systems - among them especially the ones supporting introduction of cognitive radio systems. More flexible schemes to use available radio frequencies will also emerge by introduction of spectrum sensing techniques, distribution of cognitive control information and use of commonly agreed spectrum etiquettes. From the SDR equipment architecture point of view both network-centric control schemes and autonomously operating mobile devices are equally valid in such future spectrum utilization cases.

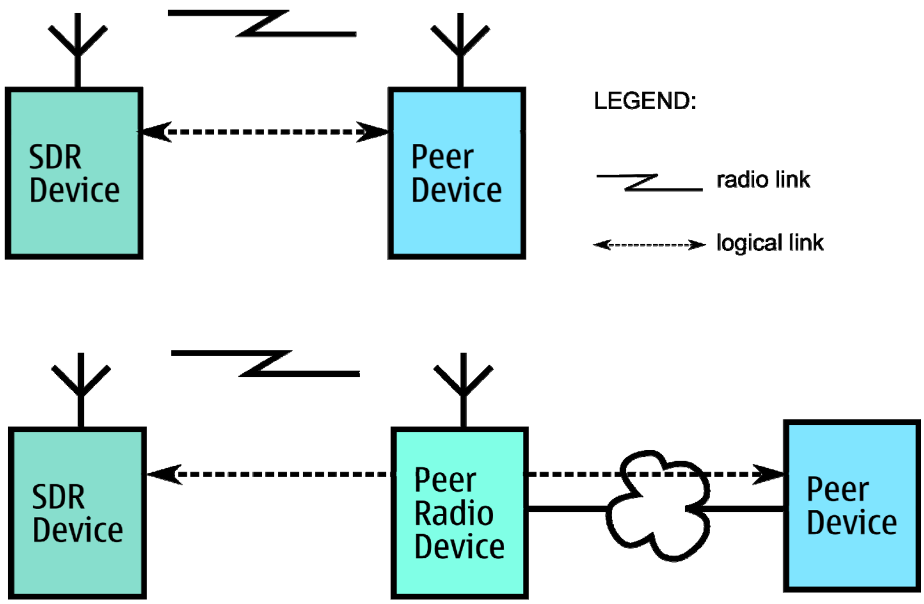

Figure 2: Operating environment of SDR mobile devices

Figure 2 illustrates the common communication cases for SDR mobile devices and can be used to fix the meaning for the following key actors present in SDR operating environment:

SDR Equipment includes those parts (subsystems) of a mobile device, which operate many - if not all - radio technologies needed to satisfy user's communication needs. Therefore SDR Equipment is considered to be a multiradio equipment and it is the primary interest of the reference architecture presented in the present document.

Peer (Communication) Equipment is any communication counterpart of a SDR Equipment. It can be reached by establishing a (logical) communications link (later on referred to as an association) between SDR Equipment and Peer Equipment. Examples of Peer Equipments are WLAN access points, IP access nodes (GGSN etc) in cellular networks, Bluetooth headsets, digital radio and TV broadcasting stations, GPS satellites etc.

Sometimes it may be necessary to distinguish between the Peer Radio Equipment (e.g. a cellular base station) and the Peer Communication Equipment (IP Access Node or GGSN in cellular network). Otherwise in the present document Peer Equipment means always a Peer Communication Equipment. As illustrated in figure 2 Peer Radio Equipments are connected with radio links and Peer Communication Equipments are connected over (logical) communications links.

5.2 Radio Computer Concept

Traditionally a radio subsystem in mobile phones and laptops has been regarded as voice telephony and data modem equipment. It has been developed as an embedded system consisting of customer logic (ASIC) components for RF and DSP processors for baseband signal processing plus protocol and control software running on a microprocessor. Recent development with advanced radio technologies (WCDMA and OFDM) has led the radio designers to look for more programmable platforms like Application-Specific Instruction set Processors (ASIP), Single-Instruction-Multiple Data (SIMD) processors as well as multicore and multiprocessor systems. Typically such architectures also need the support of some ASIC accelerators for most common signal processing functions especially due to power consumption reasons.

Instead of engineering radios as embedded systems on RFICs, special-purpose digital signal processors and ASIC accelerators, future software defined multi-radio equipment may be seen as a computer where individual radio applications are engineered as software entities to run on more general-purpose computing elements. Such a **radio computer** is capable to run multiple radios simultaneously and can change this set of radios by loading new radio application software even at run-time. Since all radio applications exhibit a common behaviour from the radio computer point of view, we call them Unified Radio Applications (URA).

In order to share the available computing, memory, communications and RF resources the radio computer has a radio operating system, just like desktop computers have their operating system. Such a radio operating system supports coexistence of multiple radios even if they are operating on same or adjacent frequency bands. Radio operating system also provides run-time reconfiguration by installing, loading and activating new radio applications.

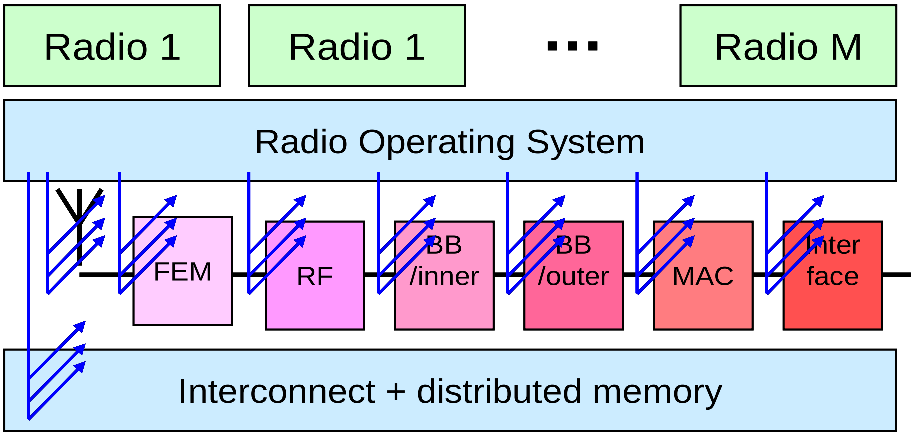

Figure 3: Radio Computer Concept

This parallelism to desktop computing leads to architecting the functionalities of a multiradio equipment as three horizontal layers: physical radio computing platform, operating system and radio applications as shown in figure 3.

The physical platform is made of seven stages, each covering both receive and transmit functions. From left to right (see figure 3) these stages comprise respectively one or multiple:

1) antennas;
2) front-end modules (filters, power amplifiers, etc.);
3) RF transceiver;
4) baseband processors for (de)modulation;
5) baseband processors for (de-)coding;
6) control processors for protocol stacks;
7) application interface units.

This multi-stage arrangement exploits structural similarities among a large variety of different radios. Each stage has to offer the appropriate amount of reconfigurability or programmability: sufficient to cover a specified set of radio standards and performance levels, but no more than can be afforded. Accordingly, the baseband signal processing part of a multi-radio computer may comprise:

- a number of programmable digital signal processors;
- a set of reconfigurable accelerators (e.g. a multi-standard Turbo decoder or descrambler);
- a number of general purpose processors.

In order to support the huge memory bandwidths required for baseband signal processing, these processors have to be supplemented with carefully designed distributed memory architecture and a flexible interconnect.

5.3 Programmable Radios

From radio developers point of view the multi-radio computer together with its operating system appears as common execution environment for radio application programs. All run-time services of the radio operating system are available as Radio Programming Interface, e.g. a set of calls to common library functions and a coherent programming model to be followed while developing radio application programs.

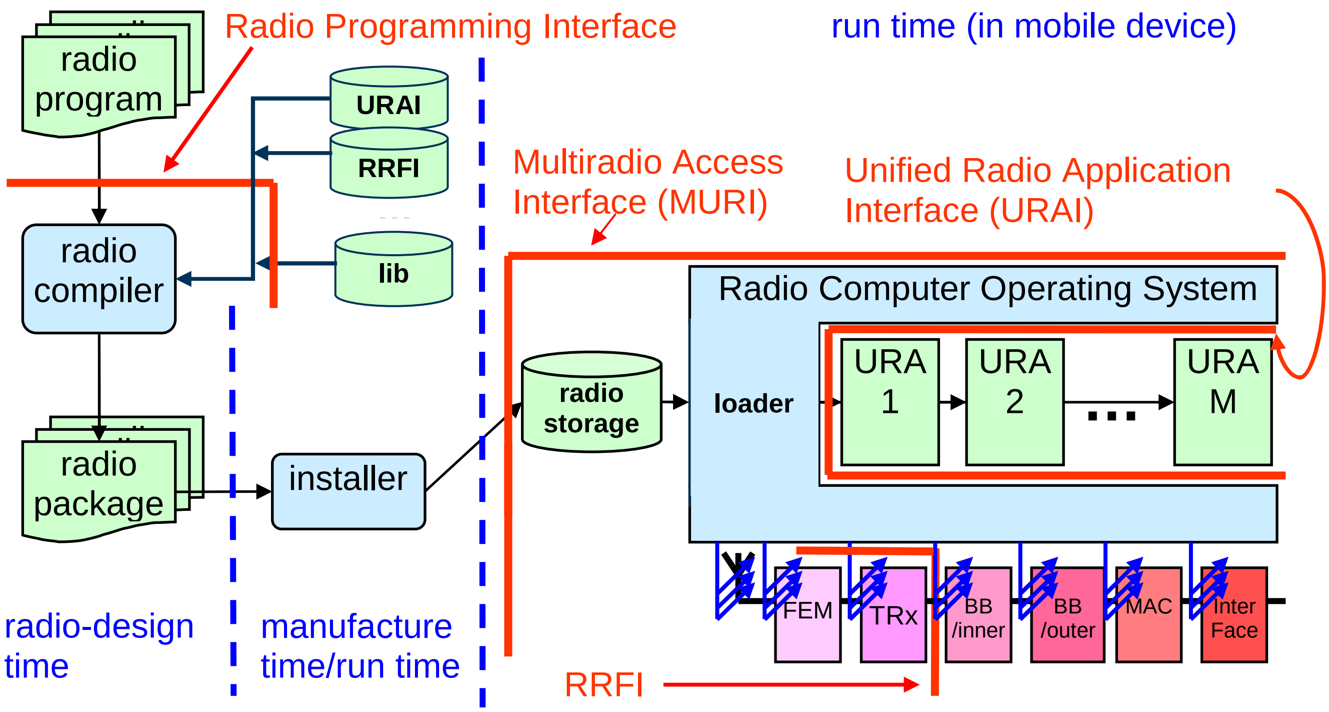

Figure 4: Compile-time and run-time functions of Radio Computer

Figure 4 illustrates a scenario, where a **radio compiler** is employed to support this kind of programming model. Radio programs are built into radio packages in compile-time. Radio package contains not only the binary code of the radio program components but also metadata about the radio system. Included into such metadata descriptions are the structure of the radio application program, radio system parameters (e.g. modes or frequency bands of multi-mode or multi-band radio systems) and also the pre-calculated run-time resource requirements, which are expressed as resource budgets.

During run-time (or if so selected already at manufacturing time) the loader component of the radio operating system will install and load radio packages into the execution environment of the radio computer. Binary code is loaded into memories available to processing elements. Radio applications are initialized with the provided radio system parameters and resource budget data is made available to the resource manager components of the radio operating system.

The four important interfaces shown in figure 4 are discussed later in clauses 5.6 to 5.9 as candidates for standardization.

5.4 SDR Reference Architecture

The functional architecture of a radio computer device is illustrated in figure 5. All services of the radio computer to its user applications are provided at the Multiradio Access Interface. The services include connectivity and data transfer, but also other kind of services like positioning and broadcasting services. User applications access the radio computer via networking stack and mobility policy manager, which maintains user preference policies for selecting radios. Additional services for installing new radio applications into radio computer are available to an administrator user.

The Multiradio Access Interface is supported by the common SDR control framework, which represents functionalities provided by the radio computer operating system. The components of this framework have different responsibilities as follows:

- **Configuration Manager (CM):** (de)installation and (un)loading of radio applications into radio computer as well as management of and access to the radio parameters of those radio applications.
- **Radio Connection Manager (RCM):** (de)activation of radio applications according to user requests and overall management of user data flows, which can also be switched from one radio application to another.
- **Flow Controller (FC):** sending and receiving of user data packets and controlling the flow.

- **Multiradio Controller (MRC):** scheduling the requests on spectrum resources issued by concurrently executing radio applications in order to detect in advance the interoperability problems between them.

- **Resource Manager (RM):** management of radio computer resources in order to share them among simultaneously active radio applications, while guaranteeing their real-time requirements.

SDR Control Framework both provides its common services to all radio applications as well as requires every radio application to provide a minimal set of common behaviour in order to be manageable as an application of the radio computer. Such radio applications comply with the Unified Radio Application concept described in clause 5.5.

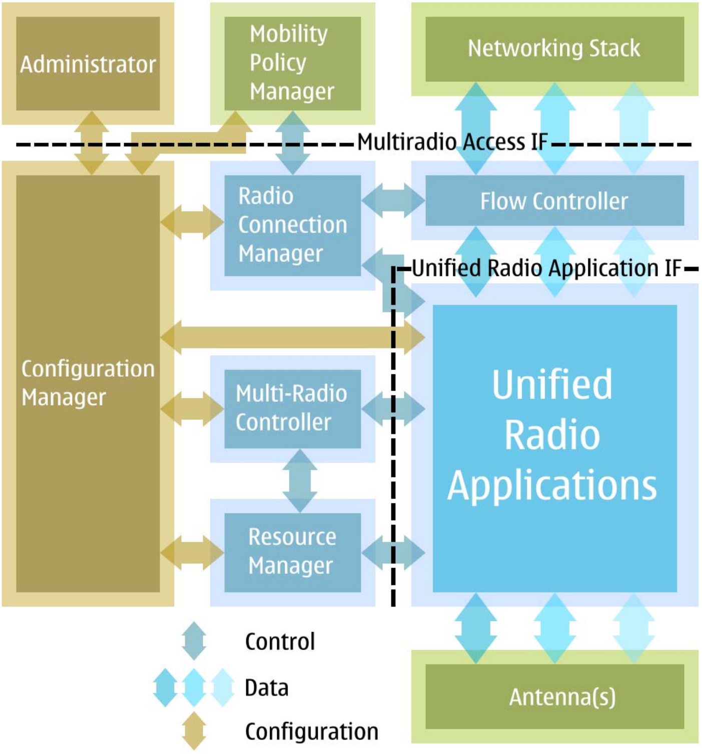

Figure 5: Functional architecture of SDR Equipment

5.5 Unified Radio Application (URA)

Following the radio computer concept, the SDR control framework allows installation and loading of radio applications during run-time. A set of radio applications may be pre-installed into the radio computer, and new ones may be brought in by using the administrator services of the Multiradio Access Interface. We describe the life cycle of a radio application inside the radio computer by using four distinct **administrative states**, which differ by their use of the shared platform resources:

- not installed;
- installed;
- loaded;
- active.

A *not installed* radio application is unknown to the radio computer. In the *installed* state, the radio computer has stored a copy of the radio package, which includes executable code for radio application and the metadata describing its resource needs and parameters. It may be stored as compressed in mass storage, for instance, for minimal memory footprint. A *loaded* radio application is available to the users of radio computer, i.e. it can be seen at the Multiradio Access Interface, but is not yet in execution. Once a copy of the radio application is in execution, it is considered to be in the *active* state, and is using the resources of the radio computer.

From the resource use point of view, the active administrative state is the most interesting. Inside the active state a set of **operational states** may be defined for a radio application to describe different resource requirements. For example, an 802.11 WLAN station that is in the power-saving mode only needs to process beacon frames sent by the access point, and has no need for any transmitter resources, leaving them available to other radio systems. If the access point indicates buffered frames for the station, or the station itself has frames to transmit, transition to normal operational state occurs.

It is the sole responsibility of the radio application designer to decide, how many and which operational states the radio application will have. By dividing the life-time of the radio application into various operational states the designer can facilitate more efficient resource sharing. Inside an operational state, the radio application is allowed to operate freely within the given limits of the granted resource budget. Transitions between operational states are triggered by the user or an external entity (e.g. radio network), and are requested from the resource manager, which keeps track of resource allocations. No real-time guarantees are given for serving these requests, and the radio application will accept also denials of state transition requests due to resource limitations. In those cases, the radio application may propagate the denial to the Multiradio Access Interface so that the higher-level control elements can take the necessary actions (e.g. deactivate lower priority radios thereby freeing resources). The SDR control framework guarantees resources for the granted operational states of the active radio applications.

The concept of Unified Radio Application may refer to already standardized radios or to new radios, which are likely to emerge e.g. from the Cognitive Radio development. New radios may become designed in such a way that they are compatible with the URA concept. For legacy radios an adaptation is typically necessary in order to make them to follow the URA behaviour. Such an adaptation will not change the already standardized behaviour of a radio device as observed by its peer radio devices. Examples of legacy radios, which may be regarded as URAs are:

- Cellular multimode GSM/WCDMA/LTE radio with standardized intersystem handovers.
- Combined WLAN 802.11b/g + Bluetooth radio with standardized coexistence on 2,4 GHz band.
- Multimode Digital Broadcast radios.
- GPS/Galileo radio for geopositioning.

5.6 Multiradio Access Interface (MURI)

Mobile device applications can access all radio computer services provided at the Multiradio Access Interface. The services include normal connectivity to Peer Equipments with uni/bidirectional data transfer. Services provided by more specific radio applications, such as positioning and broadcasting are also provided in the same uniform manner.

Three different kinds of multiradio access services can be distinguished based on the role of the user entity:

1) Access control services.
2) Data flow services.
3) Administration services.

The user of *access control* services is modelled as Mobility Policy Manager entity, which maintains the user policies and preferences on different radio access types and makes the selection between them. Modelling of such preferences and selection algorithms is outside the scope of the present document. They may originate either locally from applications or end user settings as well as in a distributed manner from network operator or from a cognitive radio management scheme.

Data flow services are typically used by the networking stack of the mobile device, e.g. the TCP/IP stack. Therefore data flow services represent the set of (logical) link layer services, which are provided in a uniform manner regardless of which radio application is actually used to maintain the link.

Administration services are user by some device configuration application to install and load new radio systems into the multiradio computer. Installation and loading may take place both at device start-up time to set up radios for constant use as well as during run-time, whenever reconfiguration of available set of radios is needed. Multiradio access interface does not make any assumption on how and when the mobile device will detect the need to reconfigure the radio computer. Receiving a new radio package for a new radio application over-the-air is just one possibility among others.

The following services have been identified as candidates to be included into the Multiradio Access Interface:

- **Radio access control services:**
  - Activate and Deactivate Radio Application.
  - Start and Stop Discovery of Peer Equipments.
  - Report Discovered Peer Equipments.
  - Create and Terminate Association with Peer Equipment.
  - Add and Delete Flow into an Association.
  - Move Flow from Association to Another.
- **Data flow services:**
  - Send and Receive Data.
  - Data Flow Control.
- **Administration services:**
  - Install and Deinstall Radio Application.
  - List Loaded Radio Applications.
  - Load and Unload Radio Application.
  - Radio Parameter Management.

5.7 Unified Radio Application Interface (URAI)

The purpose of the Unified Radio Application Interface (URAI) is to harmonize the behaviour of radio applications towards the radio computer operating system. To achieve this, all radio applications will access and provide a well-defined set of services specified in the Unified Radio Application Interface. They gain access to the shared platform resources and the radio spectrum only by using those URAI services.

URAI is a bidirectional service interface, where both provided and used services are visible.

The services provided by unified radio applications relate to activation and deactivation, peer equipment discovery and maintenance of communication over user data flows. Even though mapping of specific radio functionality to the URAI services may not always be straightforward, the benefit is that all radios can be used in the same manner.

The services provided by the SDR control framework to the unified radio applications include resource management and scheduling of spectrum access requests.

The following services have been identified as candidates to be included into the Unified Radio System Interface (the component of the SDR control framework using or providing the service from/to URA is shown in parenthesis):

- **Radio application management services (RCM – URA):**
  - Activate and Deactivate Radio Application.
  - Start and Stop Discovery of Peer Equipments.
  - Report Discovered Peer Equipments.
  - Create and Terminate Association with Peer Equipment.
  - Add and Delete Flow into an Association.
  - Move Flow from Association to Another.

- **User data flow services (FC – URA):**
  - Send and Receive Data.
  - Data Flow Control.
- **Multiradio control services for radio application (MRC – URA):**
  - Start and Stop Multiradio Scheduling.
  - Find Radio Properties.
  - Synchronize Radio Time.
  - Request and Grant or Deny of Radio Access.
- **Resource management services for radio application (RM – URA):**
  - Register Radio Application.
  - Request and Grant or Deny Operational State Change.
- **Parameter administration services (CM – URA):**
  - Register Administrative State Change.
  - Put and Get Radio Parameters.

5.8 Radio Programming Interface (RPI)

The Radio Programming Interface (RPI) shown in figure 4 has a dual role. At the time of radio application development it provides a programming interface to the developer of the radio application software. Such a programming interface assumes a common programming model and a set of software libraries. These libraries provide access to services provided by the radio computer operating system, especially URAI and RRFI services. Other libraries may be used to allow additional (platform-specific) services to be used also. During run-time the compiled equivalents of those interface libraries can be "linked" to the compiled equivalents of the radio application programs.

The underlying parallel programming model (dealing with memory and inter-task communication/synchronization) is platform neutral, and will allow an efficient mapping to a variety of different HW platforms. Platform-specific libraries can be introduced to exploit e.g. platform-specific accelerators and processors. In other words, such libraries can be used to expose platform-specific HW to the radio-application programmer.

The RPI is intended to support programming of individual radio applications in isolation, and not of collections of radio applications. The operating system is responsible for resource management, including run-time isolation of these individual radios, while providing real-time guarantees for these radios. This resource management typically involves real-time scheduling of multiple radio applications on a heterogeneous multi-processor HW architecture. Accordingly, the objective of multi-radio constrains the radio programming model to enable resource budgeting in design/compile time, and budget reservation/enforcement in run time.

The details of the RPI are dependent on the selected radio programming model, which needs to cover programming paradigms for baseband signal processing as well as for radio protocol entities. The most promising candidates identified as suitable programming models are Synchronous Data Flow (SDF) for baseband signal processing in data plane and state transition diagrams for protocol processing in control plane.

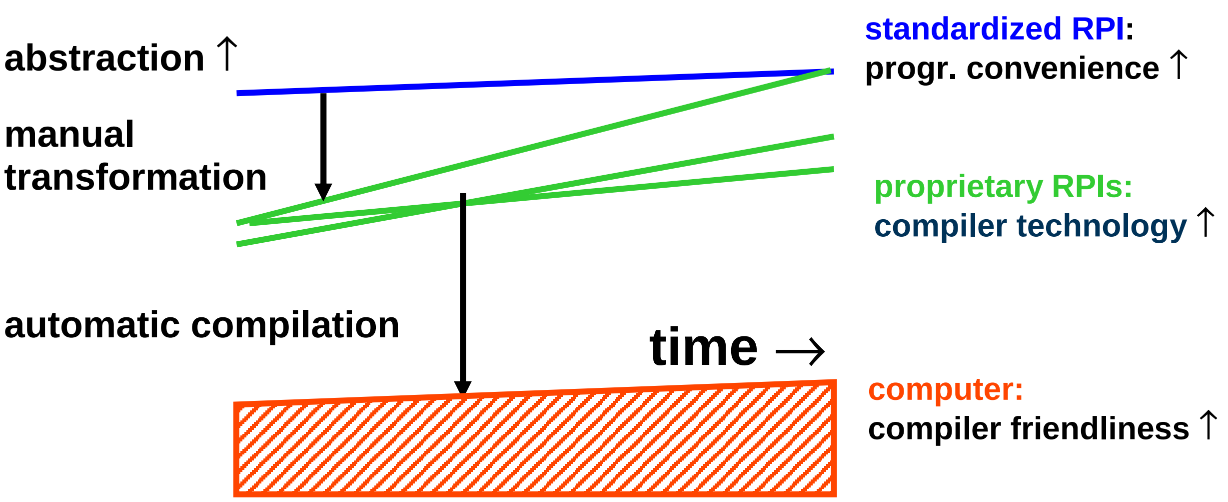

Figure 6: Evolution of Radio Programming Interface

It is unlikely that all radio computers can support the complete RPI immediately. Therefore it is anticipated that the role of the standardized RPI is to guide the evolution of radio compiler technology towards such a common goal. During an interim period the compilers need to be assisted by some manual transformation process, the amount of which is likely to decrease over time as illustrated in figure 6. Such manual transformations can aim at proprietary features and extensions of the standardized RPI, or at platform-specific libraries as indicated in figure 4. Over time, the ongoing progress in CMOS technology will make it affordable to spend some additional hardware resources (e.g. memory, processor registers, network on chip components) to simplify the compilation process, and to reduce the fraction of manual transformation. The latter is similar to evolution of DSP compilers.

5.9 Reconfigurable RF Interface (RRFI)

One of the key enabling technologies for the SDR technology is the expected emergence of flexible and reconfigurable RF circuitry, which can be shared by multiple radio applications. Although the ultimate vision of a single universal RF circuitry is out of reach, a radio computer providing a number of RF circuits for different radio technologies would benefit from more harmonized (virtualized) interface to reconfigure and use such set of hardware peripherals.

Therefore a Reconfigurable RF Interface (RRFI) inside the Unified Radio Application model has been identified as one candidate for further studies.

6 Survey on SDR standardization for mobile devices

This clause describes and collects information about SDR reference architecture related activities in other standardization bodies. The relevance of those activities is also discussed as a guidance for the further refinement of the architecture and interfaces presented in the present document.

6.1 OMG Software Radio Specification

Within the OMG Domain Technical Committee, the Software Based Communication (SBC) working group is specifically targeting development of software technologies supporting SDR and Cognitive Radio. The OMG Software Radio Specification is utilizing the Software Communications Architecture (SCA) originally developed in the scope of the US Department of Defense Joint Tactical Radio System (JTRS) program. The SCA is proposing standard solution to manage the reconfiguration of SDR equipments, known as the "Core Framework", on top of CORBA-compliant implementation constructs such as the waveform "Resource" and the platform abstraction "Devices". Due to the JTRS program procurements, the SCA is benefiting from a large industrial acceptance among the defence industry. It has not crossed for the time being the border of the defence industry towards commercial or consumer device usages.

Leveraging the SCA concepts, the OMG SBC group has developed a set of specifications for Platform Independent and Platform Specific Software Radio Components (PIM and PSM for Software Radio Components) [i.1]. These specifications are introducing the possibility, following the OMG Model Driven Architecture (MDA) approaches, to de-couple the SDR reconfiguration model from the underlying implementation technologies such as CORBA. A certain number of improvements have been brought to the initial SCA reconfiguration infrastructure concepts. An important effort has been realized as well to propose radio domain constructs, the "facilities", to enable improved characterization of the border between the software part of the waveform implementation and those parts of the useful processing undertaken by the platform. No usage of technologies based on the PIM and PSM for Software Radio Components specifications has been reported so far.

The SDR reference architecture developed by TC-RRS would certainly benefit from a model-based approach as used by the OMG Software Radio team. Another aspect, which will deserve more detailed studies is the reconfiguration management solution presented in the OMG Software Radio Components specification.

6.2 IEEE SCC41 Working Group P1900.4

The scope of the IEEE P1900.4 standardization group [i.2] is to devise a functional architecture comprising building blocks to enable coordinated network-device distributed decision making, with the goal of aiding the optimization of radio resource usage, including spectrum access control, in heterogeneous wireless access networks. In particular, a Network Reconfiguration Manager is introduced in order to control context and policy provisioning as well as network reconfiguration management; the related information is exchanged via the so-called Radio Enabler and communicated to the Terminal Reconfiguration Manager in the various terminal devices. There, the context and policy information is used in order to determine optimum link selection strategies.

The IEEE P1900.4 [i.2] architecture specification has recently passed the IEEE sponsor ballot and the publication of the specification is in preparation.

The IEEE P1900.4 [i.2] information model defined for pilot channel is expected to be of relevance for TC RRS. Furthermore, some functions of the Network-Reconfiguration-Manager as well as Terminal-Reconfiguration-Manager may be applicable.

6.3 IEEE 802.22 Wireless Regional Area Networks (WRAN)

The scope of the IEEE 802.22 working group [i.3] is to define of a Cognitive Radio based system for Wireless Regional Area Networks. Such WRAN data networking has the specific intent to be used by mobile devices in the ‘white spaces' of the TV broadcast spectrum in 470 MHz to 790 MHz frequency bands, where it will be required to ensure in particular a coexistence with television channels and PMSE devices, such as wireless microphones. The basic model consists of establishing a base station with associated mobile devices in a white space area. The important context in this group is the efforts to ensure not only protection of existing TV receivers in the vicinity but also avoiding false alarms in the sensors caused by propagation variations. A sub-group of 802.22 defines a beacon channel which reflects a very basic version of a Cognitive Pilot Channel (802.22.1).

The status of 802.22 [i.3] specifications is near finalization.

The mobile device SDR specifications developed by TC-RRS should support IEEE 802.22 [i.3] systems as possible radio applications among others such as 3GPP LTE, WLAN etc.

6.4 IEEE 802.21 Media Independent Handover

The IEEE 802.21 standard [i.4] defines media (i.e. telecommunication technology) independent access mechanisms that enable the optimization of handovers between heterogeneous IEEE 802 systems or handovers between IEEE 802 systems and cellular systems such as 3GPP and 3GPP2. The present document specifically supports handovers driven by link adaptation when the user chooses an application that requires a link quality (e.g. higher data rate) higher than the one offered by the current link.

The present document is based on a cooperative use of information available at the mobile node (network discovery, link parameters) and within the network infrastructure (network information).

The Media Independent Handover (MIH) standard consists of the following elements:

- A framework enabling services continuity during heterogeneous handover and relying on the Protocol Stack Mobility Manager of each network element.
- Handover enabling functions within the Protocol Stack of the network elements with the definition of a new entity called MIH function (MIHF).
- A MIH service access point (MIH-SAP) and its associated primitives to access the services of the MIHF, namely collecting link information and controlling link behaviour during handovers.
- New link layer service access points (SAPs) and associated primitives for each radio technology (i.e. as amendments to the standards for the respective link-layer technology).

Intra-technology (horizontal) handovers, handover policies, security mechanisms and required enhancements to link or network layers of a dedicated radio technology are not part of the 802.21 standard.

The P802.21 specification "Standard for Local and Metropolitan Area Networks: Media Independent Handover Services" was approved by the Revision Committee on October 27 2008. As of today the IEEE 802.21 group is interacting with the other 802 groups, 3GPP and ITU. Ongoing discussions are addressing:

- IMT-Advanced: seamless handover of new nomadic and mobile access networks.
- Definition of 802.21 Deployment Models.
- Support of Heterogeneous Wireless Mesh Networks.

The radio access agnostic MIH reference model includes the following abstract radio technology interfaces:

a) MIH_SAP, which defines the interface for the use of MIHF by the protocol stack upper layers (L3 network layer).

b) MIH_LINK_SAP, which defines the interface between MIHF and protocol stack lower layers (L2 link layer).

c) MIH_NET_SAP, which defines the interface between MIHF and network layer protocols used to exchange MIH information and messages with the remote network MIHF.

When considering the mapping of MIHF entity onto the SDR reference architecture elements the MIHF is decomposed into two components.

- **Local MIHF**, which implements the MIH event, command and information services on the SDR equipment side by using the URAI interface.
- **Remote MIHF**, which invokes the MIH event, command and information services on the Peer Equipment side by using the MIH protocol.

The local MIHF could be seen as part of the SDR Control Framework. The interface definitions of MIH_LINK_SAP need to be considered when refining the proposed Unified Radio Application Interface (URAI). The remote MIHF is correspondingly seen as part of the Mobility Policy Manager, which uses the SDR services via the Multiradio Access Interface (MURI).

6.5 MIPI DigRF

The Mobile Industry Processor Interface (MIPI) Alliance creates specifications for hardware and software interfaces typically found in mobile terminal systems. The MIPI Alliance is intended to complement existing standards bodies such as the Open Mobile Alliance and 3GPP, with a focus on microprocessors, peripherals and software interfaces.

The MIPI Alliance established the DigRF working group in April 2007 [i.5]. The group develops specifications for RFIC to BBIC interfaces in mobile devices. The specifications describe logical, electrical and timing characteristics of the digital RF-BB interface with sufficient detail to allow physical implementation of the interface, and with sufficient rigor that implementations of the interface from different suppliers can be made compatible at the physical level.

The group's current charter is split into short and long term development efforts. The short term development will focus on a specification targeted for LTE and WiMax air interface standards (DigRF version 4). The longer term development may include future air interface standards including possibly also support to SDR and CR technologies.

The current DigRF work covers RFIC to BBIC interface requirements on physical and protocol level with the objective to optimize interoperability between RFIC and BBIC components.

Since the DigRF WG may decide to develop similar RF-BB physical interface definitions also for the SDR equipments, the consequence is, that ETSI TC-RRS should not initiate specific standardization on the physical interface aspects of the RRFI interface in the SDR Reference Architecture. There is, however, room for ETSI to prepare a specification on logical and functional interface for reconfigurable RF.

6.6 3GPP recent progress

At 3GPP the specifications for LTE (Long Term Evolution) with a new OFDM radio technology for IP packet data are being finalized. Since LTE has been designed as an step in the continuum of GSM/EDGE, WCDMA, HSDPA, HSPA radio technology evolution, 3GPP has also created detailed specifications for LTE.

TR 125 913 [i.6] describes deployment scenarios of E-UTRA (LTE) when it is integrated with an existing UTRAN (WCDMA/HSPA) or GERAN (GSM/EDGE) network. Detailed requirements on inter-working between E-UTRA and other 3GPP systems cover radio measurements and handovers.

At 3GPP the focus is now shifting towards LTE-Advanced, which is yet another step in the same evolution chain of 3GPP radio technologies. Preliminary requirements have been released for LTE Advanced, expected to be part of 3GPP Release 10. LTE Advanced is expected to enable peak download rates over 1Gbit/s that fully supports the 4G requirements as defined by the ITU-R.

The 3GPP document TR 36.913 [i.7] outlines the migration from LTE to LTE-Advanced describing planned migration and deployment scenarios, which again underline the seamless evolution path between the 3GPP system generations. These scenarios outline the requirements for interworking and handovers to be supported between E-UTRA and Advanced E-UTRA technologies.

In order to enable smooth migration and interworking requirements between the already specified 3GPP radio technologies, i.e. GSM/EDGE, WCDMA and LTE, especially in radio base station implementations, 3GPP TSG-RAN has recently opened a new work item on Multi-Standard Radios (MSR) [i.8]. Suggestion has been that the new MSR base station standard should be developed based on a single set of generic RF requirements that meets the needs for operation of all involved RATs. A radio base station declared as MSR capable will meet the requirements and be conformance tested according to the MSR RF standard only. Discussions are ongoing whether the MSR requirements could be a new set of requirements or if complete set of single RAT requirements has to be fulfilled.

Due to the strong evolutionary design and strict interworking requirements between the 3GPP radio technologies they may be regarded as a single radio technology in the SDR mobile device reference architecture. This effectively means that and SDR mobile device may implement a set of 3GPP radio technologies as a single radio application running in SDR radio computer. Only when it regards the coexistence between the 3GPP and non-3GPP radio applications the SDR reference architecture mechanisms will be applied.

6.7 OpenMAX Application Programming Interface for Multimedia

The Khronos Group has developed a set of programming interface specifications for multimedia applications [i.9]. OpenMAX is a multi-layer programming interface aimed at the description of multimedia processing routines with full abstraction of the physical platform although making use of the potential hardware acceleration resources.

- The Application Layer of OpenMAX supports the modelling in C language of the media application based on an object oriented approach for media platform abstraction and consequently full application portability.
- The Integration Layer of OpenMAX supports the portability of the media components with a generic description of the objects and of their communication interfaces.
- The Development Layer of OpenMAX addresses the portability of the software components on hardware resources based on libraries of functional primitives mapped on hardware processing elements.

OpenMAX is supported by the Khronos Group, a member-funded industry consortium focused on the creation of open standard APIs in the media application domain. The OpenMax royalty-free standard is now fully standardized and its two lower programming levels - Integration Layer and Development Layer - are now used in commercial equipment with media components libraries available on the market:

- Integration Layer most recent version is IL 1.1.2.
- Development Layer most recent version is DL 1.0.2.
- Application Layer specification AP 1.0 is still provisional and planned for completion e/o 2008.

Beyond the difference between the respective application domains, namely multimedia signal processing versus radio signal processing, the OpenMAX specifications serve as an example on how to present a multi-layer API. This kind of parallelism can be beneficial when further creating Radio Programming Interface (RPI) specifications for the SDR Mobile Device architecture.

7 Summary and recommendations

This feasibility study documented in the present document has collected the key requirements for a SDR Mobile Device Reference Architecture which supports the different stakeholders in future SDR value network. The reference architecture outlined in clause 5 provides firm basis for more detailed studies and specifications of those architectural interfaces, which support the business of different players in such a SDR value network. According to the survey about the SDR related standardization activities in various other regional and international standardization bodies such an architecture and interfaces are yet not subjects to standardization in those bodies.

The different architectural interfaces and radio programming model are derived from the SDR value network presented in clause 4. They represent key interfaces between the different stakeholders in the value network as follows:

- Multiradio Access Interface represents the technical interface between radio computer platform providers and mobile device manufacturers.
- Unified Radio Application Interface together with Radio Programming Model and Interface represent the technical interfaces between radio application software vendors and radio computer platform providers.
- Reconfigurable RF Interface represents the technical interface between RF circuit vendors and radio computer platform providers.

As a result from this feasibility study the present document recommends that ETSI TC-RRS proceeds to create ETSI Technical Specifications for:

- SDR Reference Architecture Specification for Mobile Device.
- Specification of Multiradio Access Interface for Mobile Device.
- Specification of Unified Radio Application Interface for Mobile Device.
- Radio Programming Model and Interface Specification for Mobile Device.
- Specification of Reconfigurable RF Interface for Mobile Device.

The specification of the Reconfigurable RF Interface is expected to focus into functional RF control aspects in order not to duplicate the MIPI DigRF specification for physical interface aspects.

Each of the recommended topics may become a new Work Item under TC-RRS or they may be clustered in an appropriate way to support the ETSI Members to contribute into the specifications. The SDR Reference Architecture specification is not targeted as normative specification, but rather as a technical reference and framework for the creation of the interface specifications.

History

Document history		
V1.1.1	March 2009	Publication