Adaptive Automotive Communications Solutions of 10 Years Lifetime Enabled by ETSI RRS Software Reconfiguration Technology

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Abstract— **The vehicles typically have a lifetime of several years, possibly even longer than 10 years, over which communication technology will almost certainly evolve dramatically. The challenge of automotive communication platform is to ensure that a radio communication component remains relevant over the entire lifetime of a vehicle. A highly efficient software reconfiguration solution is introduced in this paper. ETSI Reconfiguration Radio System technology provides a suitable framework for automotive communication platform which allows to either add or replace entire Radio Access Technologies or to upgrade specific components across any of the entire layers.**

Keywords— Automotive Communication, ETSI RRS; Software Reconfiguration; Standard Architecture; Standard Interface.

I. Introduction

Automotive communication is currently a key trend in the industry. Solutions for Vehicle-to-Everything (V2X) communications, including Vehicle-to-Vehicle (V2V), Vehicle-to-Infrastructure (V2I), etc., are currently being developed. Services for automotive communications are classified into two groups, i.e., safety-related and non-safety-related. The former, of which the main purpose is to prevent car accidents, transmit warning messages related to the safety of vehicle and/or driver, e.g., abrupt brake warning massages, etc., whereas the latter is mainly for providing as efficient and/or comfortable driving environment as possible, e.g., optimization of the car moving path, transmission of the infotainment-related information, etc. Since the purpose and motivation of the safety-related and non-safety-related services are quite different from each other, the communication latency and reliability rather than achievable throughput with a given bandwidth are the main concern of the former, while the latter encounters much less restrictions on latency or reliability.

Based on the above-mentioned facts, the automotive communication platform to be adopted for the automotive communications shall be capable of supporting the various Radio Access Technologies (RAT) in accordance with the purpose and/or restrictions associated with services to be implemented for the automotive communications. For a single automotive communication platform, which can support the various RATs, to use for 10 years or more requires one essential technology, i.e., Software Reconfiguration Technology.

In this paper, European Telecommunications Standards Institute (ETSI) Technical Committee (TC) Reconfigurable Radio System (RRS) solution for software reconfiguration will be introduced. Since 2009, TC RRS of ETSI has published 6 standard documents including [1 – 6]. This set of standards will thus allow for a future-proof deployment of automotive communication platform meeting the requirements of future standards generations.

The overall structure of this paper is as follows. Section 2 introduces Mobile Device Reconfiguration Classes (MDRC) which is defined by TC RRS of ETSI. Section 3 introduces Reconfiguration Radio System for which the software architecture and system interfaces are being standardized by TC RRS of ETSI. Section 4 shows the software reconfiguration procedure of the automotive communication platform based on proposed solution. Finally, conclusions is shown in Section 5.

II. Mobile Device Reconfiguration Classes

Software Reconfiguration represents a new paradigm in radio equipment design and it will take time until a fully flexible, highly efficient platform will finally be commercially available. Rather, it is expected that a gradual increase in flexibility will be applied. For this purpose, ETSI TC RRS has defined MDRCs [1] as illustrated in Figure 1. While the exact definitions of MDRCs are given in [1], example based illustrations are used in the sequel in order to facilitate the basic understanding.

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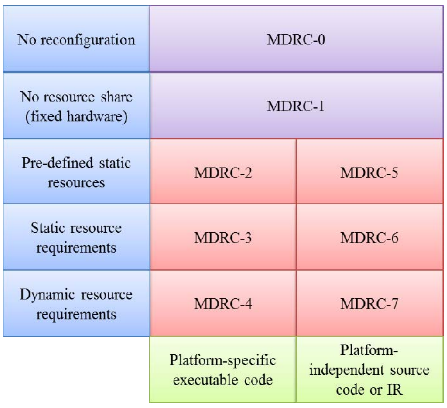

Figure 1. Mobile Device Reconfiguration Classes.

MDRC-0 (No reconfiguration) and MDRC-1 (No resource share – fixed hardware) represent today's commercial equipment. MDRC-0 does not support any reconfiguration at all and thus corresponds, for example, to a legacy Wireless Fidelity (WiFi) modem which cannot be switched to any other RAT. MDRC-1 still relies on fixed hardware implementations (e.g., Application Specific Integrated Circuit (ASIC) type of chip designs, usage of static software, etc.); however, this reconfiguration class allows the switching between multiple distinct RATs and/or to operate a multitude of RATs simultaneously.

MDRC-2 to MDRC-7 represent classes which enable Software Radio Reconfiguration. Two columns are introduced in order to differentiate between two types of code: Either Platform-specific executable code or Platform-independent source code/Intermediate Representation (IR) is provided.

In the Pre-defined static resources case (MDRC-2 and MDRC-5), these two classes implement multiple Radio Applications (RAs) but no dynamic Resource management is available.

For Static resource requirements (MDRC-3 and MDRC-6), a Resource budget is defined for each RA. This budget contains a static resource measure that represents the worst-case resource usage of the application, generated at RA compile-time.

The final stage is called Dynamic resource requirements (MDRC-4 and MDRC-7). These classes assume a similar resource manager in a reconfigurable Mobile Device (MD) as for MDRC-3 and MDRC-6, but in addition the RAs have now varying resource demands based on their current type of activity. Applications have separate operational states for different types of activity, and a resource budget is assigned to each operational state.

III. ETSI RRS SOFTWARE RECONFIGURATION SOLUTION

Since 2009, TC RRS of ETSI has been developing RRS which allows very flexible changes of RATs, i.e., addition, deletion and/or modification of air protocols through software reconfiguration without change of the hardware platform. As a result, the requirement- and architecture-related standard documents were published in 2014 and 2015, respectively. The key motivation of developing the standard architecture is to resolve the problem of portability between a RA code and hardware platform of the RRS.

A. *Standard Architecture*

The fundamental architecture of a RRS consists of Unified Radio Application (URA), Communication Services Layer (CSL), Radio Control Framework (RCF) and Radio Platform as illustrated in Figure 2 [2]. As defined in [2], the RA that is a software code implementing desired air interface(s), e.g., Code Division Multiple Access (CDMA), Long Term Evolution (LTE), WiFi, etc. can be downloaded from a public domain, e.g., RadioApps Store, to the target RRS in a form of Radio Application Package (RAP). Since all RAs exhibit a common behavior from RRS's perspective, those RAs are called URAs once they are downloaded into the target RRS.

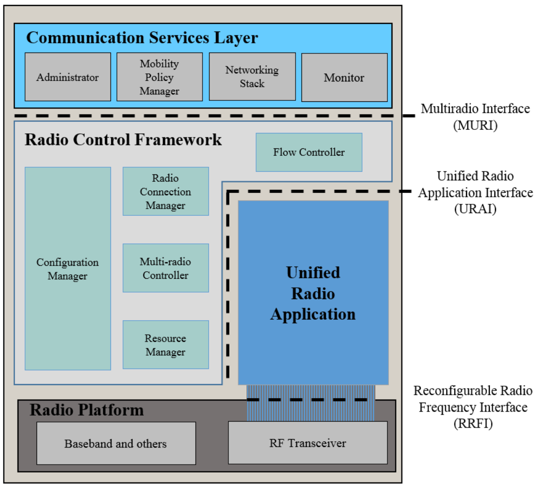

Figure 2. Reconfiguration Radio System Architecture Components.

The CSL is a layer related to communication services supporting both generic applications such as Internet access and specific applications related to multiradio applications. As shown in Figure 2, there are four entities included in the Communication Services Layer. Each of these four entities has different responsibilities as follows:

- Administrator: requests (un)installation of URA, and manages the creation or deletion of instances of URA. This process typically comprises the exchange of information on requirements for each URA, status of each URA (such as bandwidth, computational resources), etc. Furthermore, the Administrator includes an Administrator Security Function ensuring confidentiality, integrity, and authenticity of Declaration of conformity (DoC) and RAP(s), and the non-repudiation strategy.
- Mobility Policy Manager: manages the selection and association of one or multiple RATs to be operated simultaneous subject to available policies; furthermore, it gathers radio environment information, requests (de)activation of URA, etc.
- Networking stack: sends and receives user data.

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- Monitor: makes radio environment information available such as Received Signal Strength Indication, Packet Error Rate, etc. and transfers context information from the source (within the URA) to a target entity.

Another important part of the RRS is the RCF, which provides a generic environment for executing URA, and a uniform way of accessing the functionality of the CSL and individual URA. As shown in Figure 2, the RCF has 5 entities whose responsibilities can be summarized as follows:

- Configuration manager (un)installs, creates/deletes instances of URA and manages the access to the radio parameters of the URA.
- Radio connection manager activates/deactivates URA in response to user requests, and manages user data flows.
- Flow controller manages the user data traffic and related signaling.
- Multiradio controller schedules the requests for radio resources issued by concurrently executing URAs, and detects and manages the interoperability problems among the concurrently executed URAs.
- Resource manager manages computational resources in order to share them among simultaneously active URA, and guarantees their real-time execution.

The Radio Platform typically consists of programmable hardware(s), RF transceiver and antenna(s), dedicated hardware accelerator(s). Note that Radio Platform included in the standard architecture shown in Figure 2 is not a part of ETSI standard.

B. Standard Interfaces

The above described 4 components, i.e., URA, CSL, RCF and Radio Platform, are interconnected through interfaces as follows:

- MUlti-Radio Interface (MURI) for interconnecting CSL and RCF,
- Unified Radio Application Interface (URAI) for interconnecting URA and RCF, and
- Reconfigurable Radio Frequency Interface (RRFI) for interconnecting URA and RF Transceiver.

Through MURI it is possible to access all the URAs by interfacing between the RCF and CSL, see Figure 2. In order to achieve this objective, MURI provides the following services: Administrative Services, Access Control Services and Data Flow Services.

URAI bridges URA and RCF as illustrated in Figure 2, with the objective to harmonize the behavior of URA towards the operating system of RRS. URAI provides the following services [4]: Radio Application Management Services, User Data Flow Services and Multiradio Control Services.

RRFI bridges URA and RF transceiver as illustrated in Figure 2, enabling the RRS to manage the RF transceiver regardless of URA. The key functionality of RRFI is to allocate the spectral resources simultaneously or sequentially for each of multiple URAs within the spectral boundary that is physically supported by a given platform. RRFI provides the following five services [5]: Spectrum Control Services, Power Control Services, Antenna Management Services, Transmit (Tx)/Receive (Rx) Chain Control Services and Radio Virtual Machine (RVM) Protection Services.

IV. Procedure of Software Reconfiguration

The automotive communication platform that is compliant with the ETSI RRS standard architecture and standard interfaces is capable of changing the configuration of itself to support new air interfaces and/or communication protocols through the software download. It means that the platform that is compliant with the ETSI-standard architecture and interfaces can support new desired communication standards without replacing the hardware platform whenever the communication standards evolve. Furthermore, since the ETSI-standard architecture and interfaces support multiple RATs, the communication platform can provide efficient communications by selecting optimal air protocols at each given time depending upon the signal environments.

Figure 3 illustrates the procedure of updating the configuration of RRS with a new RA. Dedicated Short Range Communication (DSRC) [7] is an IEEE 802.11-based communication standard for automotive communication. Although DSRC could be used for the automotive communication at the beginning stage, considering that LTE-based V2X services are the other plausible candidates as well, vehicles that adopt ETSI-standard-compliant platform will be capable of changing its configuration from a present RAT, which is, say, DSRC, to a new one, say, LTE, through the procedure shown in Figure 3. Recalling that the functionality of automotive communication services should be guaranteed all during the life-time of the vehicle. Therefore, it can never be overemphasized the importance of the reconfigurability of the communication platform for the automotive communications because the communication standard might be changed during the life-time of the vehicle.

As shown in Figure 3, the procedure of updating the configuration of the platform with a new air interface roughly consists of 4 steps. The first step, denoted as “Installation”, is to download the new RAP into the target RRS and install the RA code of the downloaded RAP. Administrator in CSL shown in Figure 2 first requests the download of the desired RAP from the RadioApps Store. Then, Administrator sends a command to the CM for installing the downloaded RAP through the Administrative Service of MURI. Then, CM performs the URA code certification in order to verify its compatibility, authentication, etc. After certification is completed, the CM performs installation of the URA and transfers a confirmation signal to Administrator using MURI Administrative Services.

The second step, denoted as “Deactivation”, is to deactivate the old URA. The MPM in CSL first requests the deactivation of the URA (to be removed) to RCM through the Access Control Services of MURI. Then the RCM deactivates the designated URA and acknowledges a completion of the deactivation procedure using MURI Access Control Services.

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The third step, denoted as "Creating Instance", is for the activation of the new URA. The Administrator in CSL requests an instantiation of the designated URA to CM in RCF through the Administrative Services of MURI. Then, the CM requests the RM and MRC to check the use of the computational and spectral resources, respectively. The CM receives computational resource parameters and radio resource parameters from RM and MRC, respectively, for the procedure of Creating Instance. Note that the interfaces among CM, RM and MRC, i.e., the entities included in the RCF, are not included in the standard architecture, meaning that they are left as a vendor-specific. After the CM creates an instance for the URA, the CM transfers a confirmation signal to the Administrator using MURI Administrative Services.

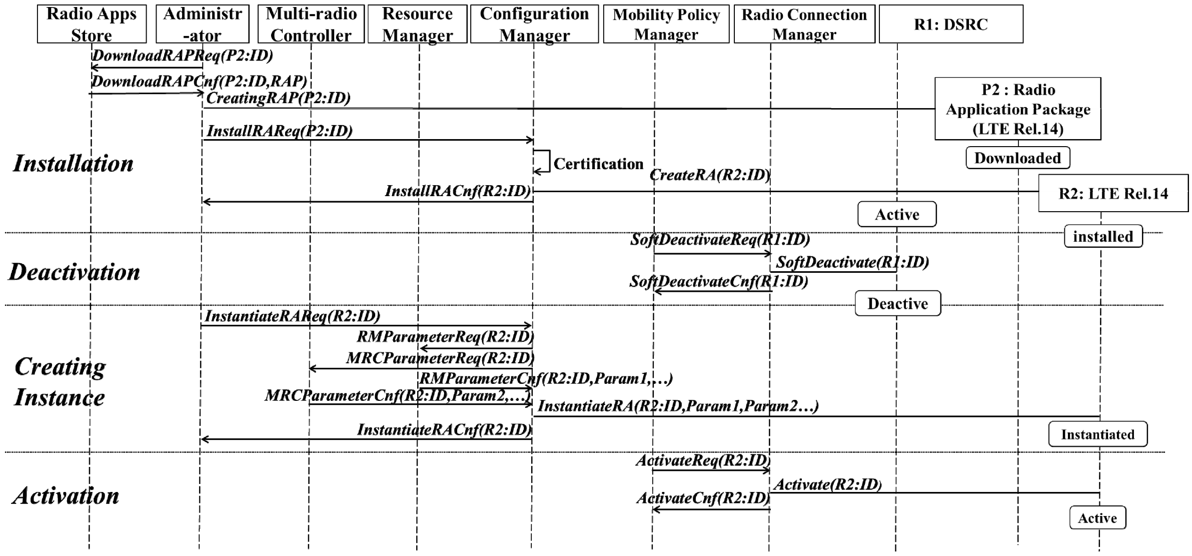

Figure 3. Procedure of RRS reconfiguration for supporting new air interface.

The last step, denoted as "Activation", is for the activation of the new air interface. The MPM in CSL requests the RCM to activate the designated URA through the Access Control Services of MURI. Upon the completion of the activation procedure, the RCM in RCF transfers a confirmation signal to the MPM using MURI Access Control Services.

The procedure of updating the configuration of the communication platform with a new RA code is completed using the above-written 4 steps. Note that the solid lines instead of arrows denote actions performed by the operating system that includes the RCF.

It is noteworthy that the feasibility of the standard architecture and related interfaces can be verified from Figure 3 through the observation that the desired RA code is first downloaded from the RadioApps Store, then installed, instantiated, and activated in RRS platform.

V. CONCLUSIONS

In this paper, a software reconfiguration solution that can be applied to automotive communication platform is introduced. In order for the communication platform of vehicles to remain valid during the life time of vehicles, the platform should be reconfigurable such that the desired communication standard, which might evolve continuously, be adopted by changing the RA code without any changing the hardware of the platform. The solution of reconfiguration provided by ETSI's TC RRS allows very efficient and commercially applicable procedures for the communication platform of vehicles be reconfigured very easily by downloading the desired RA code onto the platform.

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