Reconfigurable Radio Access Technology: Between Myth and Reality

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ABSTRACT

An overview of software radio and reconfigurable radio is given, with a special emphasis on results from EU-funded projects. The state-of-the art in reconfigurable radio is presented, detailing architectures providing reconfigurability for networks and services. The all-software approach for reconfigurable network elements and terminals is described. Finally, the Eurecom software radio platform is presented as well as the design flow for implementing reconfigurable air-interfaces. The evolution toward reconfigurable terminal architectures targeted at SoC/SoPC(System-on-a-Chip/System-on-a-Programmable -Chip) architectures is outlined.

I. INTRODUCTION

Evolving cellular networks promise to offer a variety of services requiring reconfigurable architectures capable of supporting the specific characteristics of the various networks. The resulting RATs (Radio Access Technology) must be reconfigurable in order to guarantee a certain Quality of Service (QoS) as a function of the fluctuations of the traffic, the disturbances of the radio channel and the limits imposed by the support network. Thus, the physical layer of the RAT, to ensure the negotiated QoS, must adapt access techniques, channel coding, modulations for example to take advantage of diversity mechanisms characteristic of a particular environment. In the same way, the MAC (Medium Access Control) layer must provide scheduling mechanisms in line with the QoS requirements, traffic volume and physical layer capabilities in term of available bandwidth and signal quality. This motivate the development of control layers like RRM (Radio Resource Management) able to ensure the best and possible QoS according to the available support network and constraints introduced by radio channel. To answer these requirements, various approaches are proposed, of which the most important is software or reconfigurable radio. Commercially-deployed radio networks such as UMTS already employ reconfigurable radio techniques, however limited to the constraints of the air-interface. An all-software implementation allowing full reconfigurability seems to be unrealizable for mobile terminals, which is mainly due to low power consumption requirements. This argument however is less applicable to network infrastructure elements, including the base stations. An example of an all-software base station implementation allowing the same equipment to operate with GSM or CDMA air-interfaces is commercialized by Vanu Inc (see www.vanu.com). Eurecom's Wireless3G4Free platforms (www.wireless3g4free.com) implement multi-antenna 3G base stations (UTRA-TDD) in standard PCs, and provide source-code in the public domain. To address reconfigurability in mobile terminals, we chose at Eurecom, to adopt an approach which combines the software radio approach and reconfigurable hardware architectures.

II. RECONFIGURABLE SYSTEMS : STATE OF THE ART

Since the Software Radio Workshop held in Brussels, Belgium in 1997, research in the field of the software radio did not cease evolving. Brussels Workshop was followed by the First International Software Radio Symposium organized in 1998 in Rhodes, Greece. But before all that, the interest carried to Software Radio approach was expressed during the ACTS (Advanced Communication Technologies and Services) Second Call for proposals when the project FIRST (Flexible Integrated radio system technology) was retained [1][2]. First project objective was development and deployment of Intelligent Multimode Terminals. During the ACTS third Call for proposals, two projects resulted in software radio area: SUNBEAM (Smart Universal Beam-forming) and SORT (Software Radio Technology). One dealing with the integration of smart array antennas in "Software Radio Base Station", the other looking into base station issues. The dedication of the software radio research orientation clearly appeared within ESPRIT research program (M3A: Mobile Multi-Media Access Using Intelligent Agents, SLATS: Software Libraries for Advanced Terminal Solutions) and with the framework of the IST (Information Society Technologies) projects, 5th Framework Programme especially with projects like CAST (Configurable radio with Advanced Software Technology), DRIVE (Dynamic Radio for IP-Services in Vehicular Environments) and OVERDRIVE (Over Dynamic Multi-Radio Networks in Vehicular Environments), MOBIVAS (Downloadable MOBIle Value-Added Services through Software Radio &

Switching Integrated Platforms), PASTORAL (Platform And Software for Terminals: Operationally Re-configurAbLe), TRUST, WIND-FLEX (Wireless Indoor Flexible High Bitrate Modem Architecture), SCOUT (Smart User-centric Communication Environment), STINGRAY (Space Time codING for Reconfigurable wireless Access sYstems) , MOBY DICK (Mobility and Differentiated Services in a Future IP Network). This European orientation was followed by national research projects like PLATON (PLATe-forme Ouverte pour les Nouvelles générations de systèmes mobiles) in France, which resulted in the Eurecom open-source real-time platform. It was supported during IST 6^{th} Framework Programme through several projects. The most important one totally dedicated to reconfigurability issues is E^2R (End to End Reconfigurability) [3]. Software radio techniques are also used in the context of the WIDENS (WIreless DEployable Network System) project which aims at rapidly deployable, self-organizing and reconfigurable AdHoc networks in support of broadband public-safety applications. Here, reconfigurability features in the network are of utmost importance especially in emergency situations.

All these projects aim at achieving a high level of reconfigurability and propose solutions for realizing SDR at different levels as shown on figure 1.

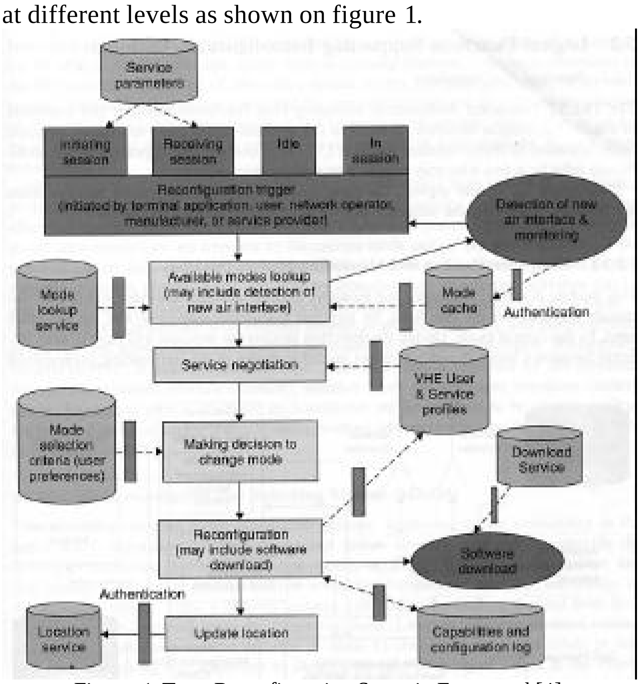

Figure: 1, Trust Reconfiguration Scenario Framework[4]

As we can see from the last figure, reconfigurability issues concern mobile terminals as well as network. At the mobile side, mobility of the user, traffic demand, service fluctuations, radio channel perturbations increase the need for reconfigurable mobile terminals to ensure inter-system operability, flexibility, scalability, and to guarantee a required QoS. Thus, reconfigurability can be considered at different levels:

1. Network based reconfigurability: Inter-operability requires multi-mode, multi-standard and multi band terminals to be compatible with various networks hosts that the mobile experiences during its moving.
2. Service based reconfigurability: Depending on the application, the radio channel, the ongoing traffic, mobile terminal has to reconfigure its architecture in accordance with its capabilities to guarantee QoS requirements.
3. User based reconfigurability: To provide user desired services with affordable QoS.

In 3G networks and beyond, mobile service provision is expected to change substantially, leading creation of an open market, where entities such as independent Value Added Service Providers (VASPs) and content providers will be able to contribute to the development of diverse services which will be targeted to a variety of environments besides cellular mobile networks [5] as shown on figure 2.

Adequate support for such services cannot be provided by fixed network architecture. Thus, more flexible networks that can adapt dynamically their architecture to provide user desired services with some guaranteed QoS are needed.

To address all these reconfigurability aspects, advanced reconfigurability management and control features must be introduced at various layers. In particular:

1. service provision based reconfigurability management
   - QoS provision
2. Policy based reconfigurability management
   - Charging and billing
3. Network, terminal and user profile based reconfigurability management
   - Monitoring functionality in the network.
   - RAT reconfiguration

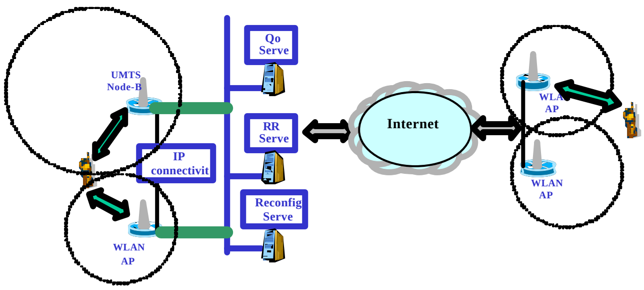

Figure: 2, Reconfigurability management in heterogeneous mobile cellular networks

IV. Pure software approach

To reach the maximum level of reconfigurability, researchers and designers have proposed different solutions. One consists of a pure software approach with RAT consisting of a reconfigurable chain formed by different software components available in database libraries. IST TRUST [4] project within 5th Framework programme, follows this approach and was entirely dedicated to address all the reconfigurability aspects at the mobile side [7][8][9]. The research efforts carried out in this project were oriented to investigate mobile terminal capabilities, called RUT (Reconfigurable User terminal), to be able to adapt its architecture in order to reach high all the reconfigurability levels mentioned above especially that one related to multi standards issues. The key idea is for the mobile is the software download as shown on figures 3 and 4.

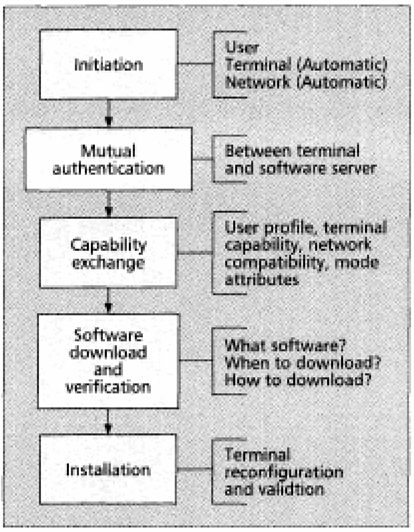

Figure: 3, Generic software download flowchart [7]

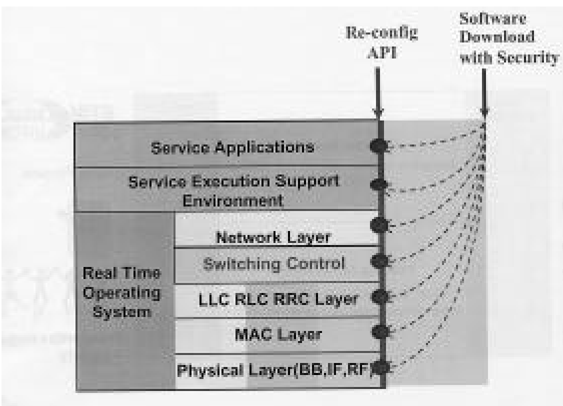

Figure: 4, Software download with security issue at different layers [6]

It consists of software patches, software upgrades licenses and keys, install scripts, validation test cases and device configuration files. There are different categories that can be downloaded in device: Application and service provisioning, RAT protocol software, analog and digital signal processing software, etc.. TRUST proposes also to manage the handoff mode between different RATs. This is called mode switching and is shown on figure 5. It could be triggered by the network in order to perform load balancing between different systems or to downgrade the QoS used by some users in favor of other users.

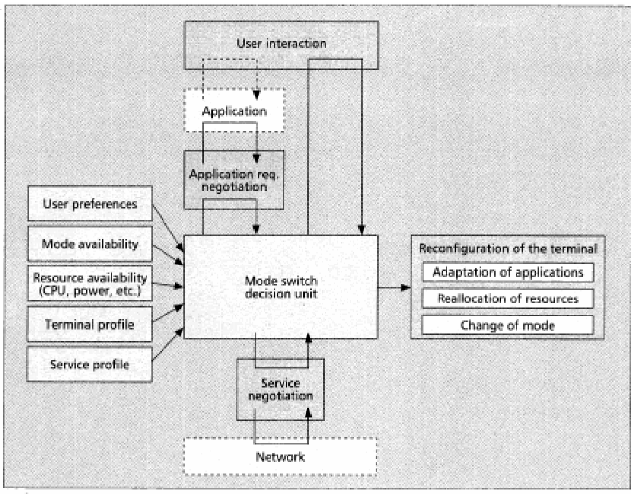

Figure: 5, Interactions between mode switching decision unit and related entities [7]

This extended notion of reconfigurability based on pure software approach could be feasible if the network infrastructure provides support terminals reconfiguration (software download, handoff decision making…). Systems supporting that approach require software architectures that offer a reasonable split between terminal and network infrastructure.

Note that, because of software download based strategy, there are many problems related to security which were addressed in many European projects.

The security issue has been recognized as vital for Software Radio in a number of works [10] [11]. It includes different aspects as:

- Privacy
- Integrity
- Authentification

This confidential nature of secure software download is generally based on the use of cryptographic components which could take at each transaction a long time before authorizing the mobile to access to the network. [12] presents some performance of these cryptographic components in terms of the amount of exchanged data, the execution tin time and the mobile target architecture. In certain scenario (high speed mobility, fast handoff…), these low performances could be prejudicial for the success of the requested connection.

V. EURECOM'S APPROACH TO SOFTWARE RADIO

Eurecom has developed a true software radio system for 5MHz channelization making use of standard PCs and the open-source POSIX-compliant hard real-time operating systems, RTLinux and RTAI. Although the architecture is quite generic, a complete implementation of the access-stratum of the UTRA-TDD third generation mobile communication system has been implemented as reported in detail in [13] and can be downloaded from the website http://www.wireless3g4free.com. The system includes networking elements such as RRM for combining radio-resource and reconfigurability management in an pure-IP architecture.

Test deployments using RF sub-systems in the 2GHz band are being carried out in the context of several European (FP5/FP6) European and French National collaborative research projects. Specific issues related to reconfigurability of radio systems are studied and make use of the system in the FP6 WWI project E^2R. A reconfigurable OFDM-based air interface for rapidly deployable AdHoc public-safety networks in the 5GHz band along with a wideband (4-6 GHz) radio front-end are being developed in the context of the FP6 project WIDENS. The wideband nature of the radio aims at demonstrating spectral agility and reconfigurability of the RF sub-system.

The software elements of the Eurecom platforms are shown in Figure 5. The radio-interface is implemented as a set of POSIX threads using the RTLinux/RTAI micro-kernel and dialog with the RF subsystem via the standard PCI bus. Networking functionality is provided by the IPv4/IPv6 protocol stack in the Linux kernel, allowing for standard IP-based applications to be used. In addition, entities responsible for RRM dialog with access-elements (e.g. base stations, relays, etc.) via the IP-backbone.

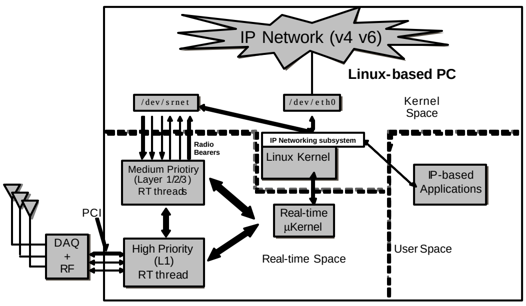

Figure: 5, Eurecom Software Radio

Software Radio Design Flow

Our design flow consists first of algorithm development in the C language. In addition, protocol layers could be implemented with the aid of code generation/validation tools such as ESTEREL Studio. An example of this was the development of the Radio Resource Control Signaling mechanisms for UTRA-TDD.

As radio protocols typically involve mechanisms operating on different time scales (e.g. modulation, channel coding/decoding, retransmission protocols, signaling mechanisms, etc.) a multi-threaded priority-based organization is used. For example, the UTRA-TDD process scheduling mechanism uses 5 time scales with different processing-delay constraints, corresponding to time-slot processing (666us periodic scheduling for modulation/demodulation) and frame processing on the 4 UMTS time-scales (10,20,40,80ms periodic scheduling for error decoding, MAC, RLC and RRC layers) as discussed in [13]. The radio interface is therefore described by a finite-set of threads which are scheduled based on their priority in order to guarantee real-time constraints.

In order to validate the scheduling of different sub-systems within the radio interface and to simulate the full functionality of a radio network we have developed an RF network simulator running on a PC network (or even a single machine) which uses TCP/IP sockets to exchange digitized signals (complex baseband equivalent) between radio nodes (terminals, base stations, etc.). It is shown in Figure 6 where the nodes are labelled according to two categories (RG = Radio Gateway or evolved base station, MT= Mobile Terminal). A centralized server, dubbed a "Channel Server", aggregates the signals from the nodes and simulates the radio network impairments (path loss, multipath propagation, thermal noise) and then distributes the channel output back to the nodes. The code executing in each node is the full multi-threaded radio interface but in user space. It executes more slowly than during real-time operation due to the signal transfer mechanisms on the Ethernet network. This simulation system allows for validation of the full system in the simulated target environment (i.e. RF interaction between radio network elements) as well as simulation of the radio-specific performance measures (e.g. error-rates, packet delays, etc.). This allows the system designers to debug the **full-functionality** of the system before testing in real-time with the true RF sub-system.

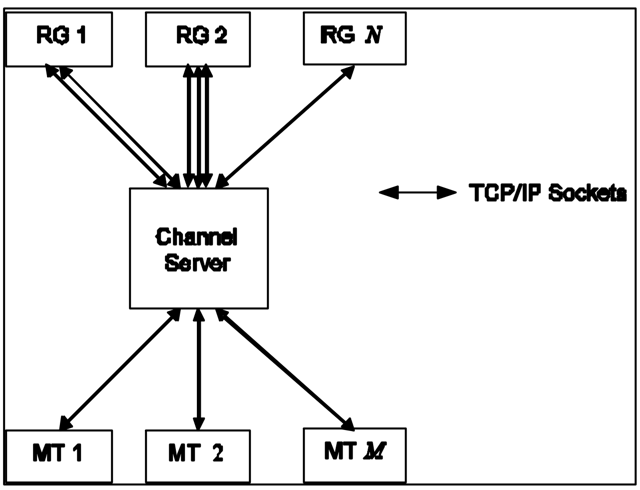

Figure: 6, Radio System Functional Simulator

The final step in achieving real-time performance is the identification of critical code sections and optimization of signal processing algorithms. For PC platforms this requires the use of the fixed-point SIMD instructions (MMX/SSE/SSE2). We have highly-optimized routines available in the public domain for 3GPP modems and OFDM-based modems (e.g. matched filtering, pulse-shape filtering, FFT, Viterbi decoding, Turbo decoding, etc.).

HW/SW Partitioning for SoC/SoPC platforms

In order to exploit our developments in low-power consumption devices (e.g. mobile terminals, pico-basestations, etc.) certain portions of the software implementation must be ported to dedicated hardware. We adopt an approach where we port the all-software architecture to an hybrid hardware/software architecture. Work is this direction is being carried out in collaboration with the ENST Sophia System-on-a-Chip group (LabSoC, www.enst.fr). The approach consists of using SoC/SoPC (System-on-a-chip, System-On-A-Programmable-Chip) architectures combining a low-power processor core with reconfigurable signal-processing co-processors. The co-processors will typically play the role of the optimized code sections in the all-software approach. The control mechanisms and protocol layers remain unchanged and execute on the processor core. For prototyping we make use of Virtex2Pro FPGAs which incorporate embedded PowerPC processors running RTLinux/RTAI. These techniques could be used to design multi-mode wireless devices by using a set of generic coprocessors and several radio interface implementations in software.

VI. CONCLUSION

The state-of-the-art in reconfigurable radio was presented, detailing architectures providing reconfigurability for networks and services as well as user-centric protocols in order to provide the desired level of QoS in the most efficient manner possible. The all-software approach for reconfigurable network elements and terminals was described, although it seems to be unrealizable for present-day user terminals. Finally, the Eurecom Wireless3G4Free software radio platforms were presented as well as the design flow and validation tools for implementing reconfigurable air-interfaces. The evolution of the all-software approach towards reconfigurable terminal architectures targeted at SoC/SoPC(System-on-a-Chip/System-on-a-Programmable -Chip) architectures was briefly described.

VI. REFERENCES

[1] W. H. Tuttlebee, "Software Radio Technology: A European Perspective", IEEE Communication Magazine, February 1999.

[2] J. Mitola, "The Software Radio Architecture", IEEE Communication Magazine, May 1995, vol. 33, pp. 26-38.

[3] For information on E^2R, see http://www.e2r.motlabs.com

[4] IST-1999-1070 TRUST Project, Delivrable D4.2, "Report on proposed novel solutions on SDR system features", November 2000.

[5] M. Dillinger, K. Madani, N. Alonistioti, *Software Defined Radio*, England: Wiley, 2003.

[6] M. Dillinger, K. Cook, G. de Boer, "TRUST: An overview", SDR Forum meeting, 2000,

[7] M. Mehta, N. Drew, G. Vardoulias, N. Greco, C. Niedermeier, "Reconfigurable Terminals: An overview of Architectural solutions", IEEE Communication Magazine, 2001, vol. 39, pp. 82-89.

[8] J. Pereira, "Beyond Software Radio, Towards Reconfigurability Across the Whole System and Across Networks", IEEE VTC, 1999, pp. 2815 -2818.

[9] IEEE Commun. Mag., Special Issue on Software Radio, 1999, vol. 37, no.2, pp. 82-112.

[10] L. B. Michael, M. J. Mihaljevic, S. Haruyama, R. Kohno, "Security Issues for Software Defined Radio: Design of a secure Download System", IEICE Trans. Commun., January 1999.

[11] Software Defined Radio Forum, www.sdrforum.org

[12] L. B. Michael, M. J. Mihaljevic, S. Haruyama, R. Kohno, " A proposal of architectural elements for implementing secure software download service in software defined radio **",** Personal, Indoor and Mobile Radio Communication, The 13th IEEE International Symposium, 2002, vol. 1, pp. 442-446.

[13] C. Bonnet, L. Gauthier, P.A. Humblet, R. Knopp, A. Menouni Hayar, Y. Moret, A. Nordio, D. Nussbaum, M. Wetterwald, “An all-IP Software Radio Architecture under RTLinux,” Annales des télécommunications vol. 57,no. 7-8, July-August 2002