A SOFTWARE RADIO APPROACH FOR THE TRANSCEIVER TRANSITION FROM 2G TO 2.5 G TO 3G

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ABSTRACT

This paper illustrates that the *software radio approach* is of great interest in the context of future multi-standard environments that will become prevalent as we move towards and beyond 3G. Software radio can facilitate this transition thanks to the digital approach that is associated with. The time has come for experimentation and concrete demonstrations that will permit to better understand key issues and establish the merits of the technology. A complete software radio case study is presented here. This case study concerns a real-time triple mode implementation of the GSM-EDGE-UMTS modulation and demodulation schemes using a software centric approach and state-of-the art DSP components. Implementation details and performance results are given.

This work together with other efforts around the world demonstrates that SWR will be a key technology factor for the transition from 2G to 3G and the evolution of mobile communications in general.

1 INTRODUCTION

Life after 3G as a question can be misleading in the sense that it is quite certain that the future will be characterized by the co-existence of several generations. In a global scale clear cut generation frontiers do not exist. 1st generation found well its way into the 2G era and the same will happen during the transition period to 3G via 2.5G. One can say that transition periods tend to become permanent states of affairs because as long as existing standards represent investment, allocated spectrum and user base they will simply continue to exist and evolve. Finally, considering that 3G is not a single standard but a family of regional standards it is certain that in the road to 4G it will evolve either by the addition of new standards prompted by the introduction of new services (and thus new requirements) or by the evolution of the existing standards to more efficient versions. Such visions are explained in detail in [1], [2]. As markets become global and as networks become more and more diversified, heterogeneity at various levels increases. Software radios (SWR) and *re-configurable radios* (RR) in general, come as an answer to the problems posed by this heterogeneity.

SWR is an ecological way of designing communication systems as it permits to propose a single (common) hardware solution for the global market, to benefit from a multi-standard system, to share IPs with the rest of the community, to increase the life duration of the deployed equipment (*future proofing*) thanks to its re-configuration properties. These benefits concern not only OEMs but also network operators and by extension the final users. Let's just note increased upgradability, flexibility and versatility offered by SWR solutions.

Exploiting the full potential of RR technology will not happen overnight but it will happen in a rather incremental manner. First, the required technologies still need to advance to deliver the required performance. Second, RR has a deep impact on several crucial issues (networks, business models, deployment roadmaps), as [3] indicates, that need to be studied. Such issues prompt for research and standardization activity and will be briefly outlined in the last part of this paper. The rest of this paper is devoted to a SWR case study relevant to the scenarios corresponding to the transition towards 3G as well as the need to operate in multi-standard environments. The involved modulation schemes correspond to the standards that mark the evolution of cellular communications towards and beyond 3G. For Europe these are: GSM, EDGE and UMTS. Implementation results will be presented. Finally, a brief view of the worldwide SWR context will conclude the discussion.

2 A SWR CASE STUDY

Before going further a definition is in order. The terms software radio (SWR) and re-configurable radio (RR) will be used interchangeably throughout the paper to denote a radio communication system whose operation (air-interface) can be modified by changing the contents of some memory whether this is the program of a processor, the configuration bitstream of an FPGA, the parameter values of functional blocks (both hardware or software). The system is designed in order to provide for this change which is performed via some implemented re-configuration mechanism. The re-configuration process is triggered by some re-configuration policy which is particular to the operational context of the RR equipment.

Though the scope of SWR is very broad, this paper concentrates on a very specific aspect: the *digital-software* implementation of a broad set of modulation and demodulation schemes on the same generic hardware platform. In addition for this work we make use of wideband A/D-D/A components and of last generation VLIW DSP processors that permit very fast execution of high-level language programs. It will be shown that it is possible to realize in software high-data rate functionality, IF processing (including frequency translation) extending the current practices of using DSPs only for low data rate simple baseband functions. Through detailed performance measurements we obtain concrete evaluations and not simply estimations of the various components.

2.1 The modulation schemes under study

The details of the modulation schemes (modulation and pulse shaping) for GSM-EDGE-UMTS are summarized in table 1. Such a wide panel of modulation schemes (GMSK, offset-8PSK, QPSK respectively) and different pulse shaping permits to get a global view on the requirements of multi-standard operation.

Standard	Modulation characteristics	Pulse shaping Tx	Rx	Required performance symbol rate, bit rate
UMTS	QPSK preceded by DS-CDMA	RRC roll-off: 0.22	RRC	3.84 Mchip/s
GSM	MSK with gaussian filter	Gaussian BT: 0.3	free	270.833 Ksym/s 270.833 Kbit/s
EDGE	3p/8 offset 8-PSK	Gaussian	free	270.833 Ksym/s 3 x 270.833 Kbit/s

Table 1. Case study modulation schemes

2.2 The experimentation hardware platform

In [4] our view relating to SWR system design for re-configurability and re-configuration is given. In this spirit our SWR R&D activity is based on a generic reprogrammable/re-configurable hardware platform. It consists of wideband interfaces to the analog world and abundant DSP processing nodes based on state of the art VLIW DSPs (currently the TI C6201 at 200 MHz). Most of its functional aspects are under software control. An Ethernet TCP/IP based link assures connectivity to a backbone network. Several tools exist to assist in the system development process. The use of very fast VLIW DSPs permits to develop efficient code entirely in C language which enables rapid development, fast debugging and increased code portability.

This platform has many desirable characteristics. First it can scale to application processing demands by adding more processing nodes. Second it can be extended to incorporate other technology with high importance to re-configurable radio systems, i.e. FPGA. Finally, the network connection permits, if needed, to study the RR impact on network issues as well.

Nevertheless it must be underlined that currently in our platform the RF is section issues are not considered. A solution for an RF multi-standard implementation could be the one shown in figure 1 where the RF flexibility is achieved by hardware replication which has drawbacks when cost, size, power consumption and components count are considered.

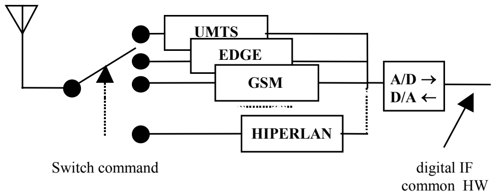

Figure 1. Flexible RF section

Taking advantage of technology progress IF acquisition using *undersampling* techniques [5] is now a reality. Real-time digital processing at some IF is completely affordable for GSM, EDGE and UMTS with today's processor technology. The SWR area is now technically open and permits to consider a common hardware solution following the A/D/A stage.

It must be noted that currently the TI C6x DSP processor family targets mainly infrastructure equipment. Due to its high power consumption, size and price it is not destined for mobile terminals. Nevertheless the implemented concepts and DSP techniques apply to both cases.

2.3 Experimental results

Transceiver performance was considered in terms of both quality of the transmitted signal and of the computation speed. The same hardware is able to support all three GSM-EDGE-UMTS modulation/demodulation schemes just by changing the DSP software and software controlled configuration parameters. Implementation parameters to be taken into account are those of table 1. Based on these parameters the generic transmission chain of figure 2 is configured for each standard.

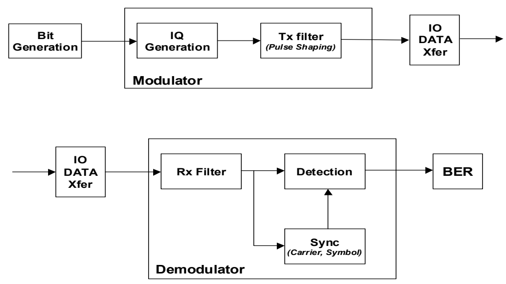

Figure 2. Generic Transmit/Receive chains

For the case study we consider single processor implementations for the Tx, Rx chains in order to evaluate the processing demands of each standard on the processor architecture. Our platform permits to experiment with two types of implementations. In the first digital-IF processing including frequency translation is implemented by programmable ASICs (digital up/down converters DUC/DDC). In the second implementation alternative all processing (including frequency translation) happens in software. Results for the GSM, EDGE modems are given for the digital SW+ASIC implementation whereas for UMTS the *all-software* implementation is used.

For the trigonometric computations used in GSM [6] and EDGE [7] the CORDIC [8] algorithm was used which offers flexibility and can trade-off result accuracy for speed. For the GSM GMSK receiver a differential detection approach is used that permits to avoid implementing carrier phase recovery. Symbol clock recovery is achieved digitally by using an oversampling factor of 4. For the rest of the coherent detection schemes (EDGE, UMTS) carrier phase recovery is performed digitally and digital interpolation techniques are used for symbol clock recovery. AFC is not performed though independent Tx and Rx oscillators are used.

Modulation quality measurements

The modulators were validated using a *vector signal analyzer* (VSA). *Error Vector Magnitude* (EVM) figures reveal quite satisfactory. EVM gives the deviation of a received constellation from an ideal reference constellation, and so provides a good indication on transmission quality. Compared to existing EVM figures for mobile terminals the results of table 2 reveal very satisfactory.

Modulation	IF	EVM (% rms)
GSM	2 MHz	1.24
	10 MHz	2.32
EDGE	2 MHz	0.159
UMTS	1 MHz	2.09

Table 2. Error vector magnitude (EVM)

Execution speed measurements

Several performance measurements were obtained for the software execution speed on a TI C6201 DSP with a 200 MHz clock. From CPU cycle counts the attained data rates are derived. The results are given in table 3. We measured the global performance of the Tx, Rx chains as well as the performance of only the modem functionality, i.e. modem and pulse shaping functions.

Modem	Required Perf. kbits/sec	Tx		Rx	
		Full Chain	Modulator	Full Chain	Demodulator
GSM	270.83	397.85	444.6	622.45	753.56
EDGE	812.49	2353.77	3107.95	1329.27	1520.19
UMTS	3840	2264.23	2868.49	2260.29	2870.6

Table 3. Attained bit rates (chip rate for UMTS)

It can be seen that for single processor implementations of Tx , Rx for GSM, EDGE the attained performance is higher than the required by the standard. For UMTS a single C6201 processor cannot deliver real-time performance and so multi-DSP alternatives need to be considered. However the C6x roadmap shows that soon processors at 1GHz clocks will be available (i.e. C64x).

The present measurements indicate that a single C6x could eventually handle both Tx, Rx at the same time and deliver real-time performance also for the UMTS modem. Having the software written in high-level language code will permit to easily take advantage of technological progress in processor design and manufacturing.

Computation load distribution

Another set of measurements investigates how processing time (load) is distributed among the transceiver functional blocks. These measurements, shown in figure 4, give good indications which are the functional blocks to optimize or to implement on reprogrammable hardware (e.g. FPGAs). To read the results for each standard the generic chain of figure 3 was instantiated to implement the required functionality. The UMTS chain is shown in figure 3.

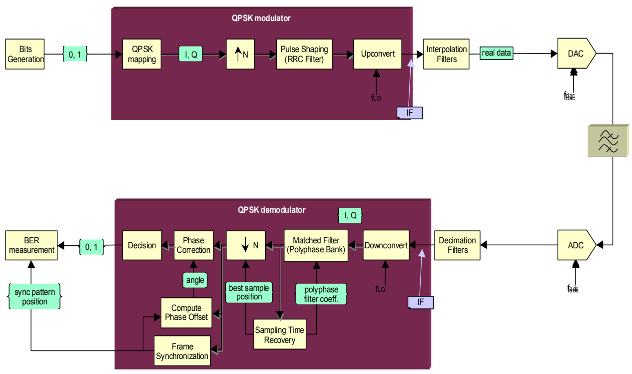

Figure 3. UMTS full-software transceiver

For the GSM Tx the method of [9] can further increase performance considerably by precalculating the pulse shaping filter response and eliminating the trigonometric calculations for I, Q generation. In addition a coherent detection scheme for Rx may eliminate the computation overhead of the CORDIC based trigonometric

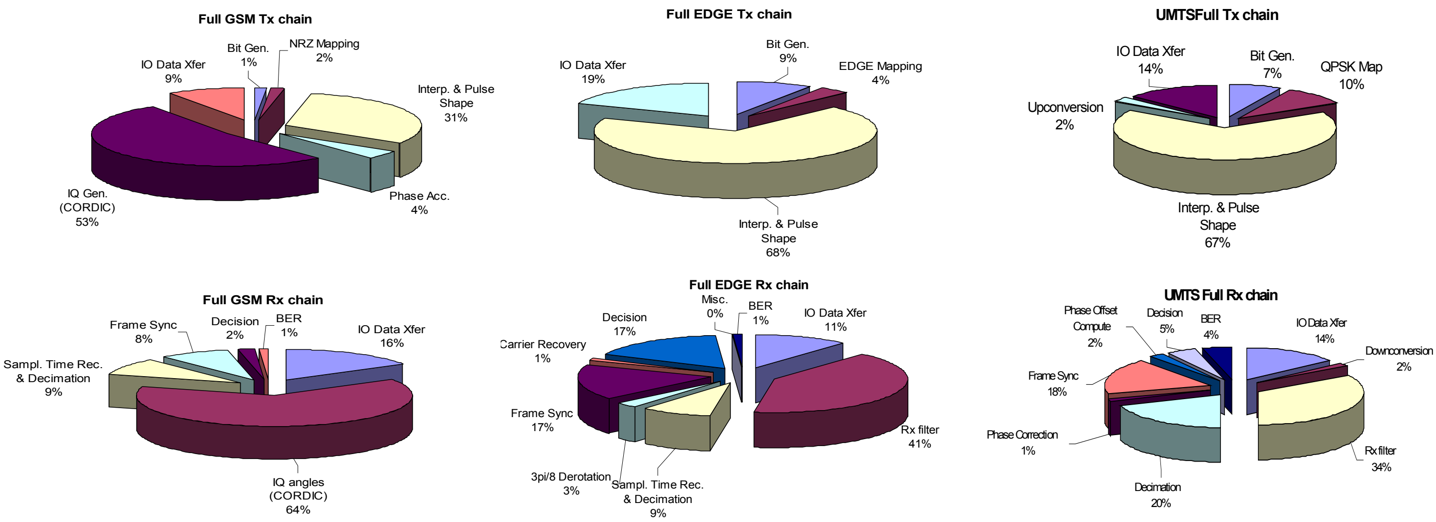

Figure 4. Processing time decomposition in Tx and Rx for GSM, EDGE and UMTS

computations.

It is clear that filtering for pulse shaping though a simple operation it is the most time consuming. This gets more pronounced for higher oversampling factors which may needed in order to simplify other functional blocks (e.g. carrier/symbol synchronization). Such simple (regular) but time consuming processing is a good candidate for a more hardware oriented implementation. For instance FPGA implementations are very interesting because they permit to retain the flexibility offered by reprogrammability.

3 SWR WORLDWIDE ACTIVITY

This section gives a summary of the SWR worldwide activity and presents the established vision of how SWR will progressively gain acceptance.

Starting in the use US initially for military applications, the SWR concept made its first steps and evolved into what is called *software defined radio* (SDR). From such efforts the SDR Forum [10] spawned in order to create consensus on technical issues (e.g. definition of an open architecture, interfaces for interoperability and software download issues). However, so far the impact of SWR on the cellular networks has not been a core issue within SDRF. In this aspect European research, through collaborative IST projects, tries to address such issues according to the vision defined in [11], [3] with SWR being a key technology in the evolution beyond 3G. Finally, in Japan, Korea and China there is a vivid interest in SWR technology and its applications as [12] shows.

At a first time we shall see the capabilities of re-configuring at the application level (using WAP, MExE, Java etc.) mature and gain acceptance. Re-configuration of radio functionality will build upon these existing mechanisms. The SDRF [10] in collaboration with ETSI and FCC is proposing extensions to MExE in order to cover the requirements for physical layer re-configuration under the same framework. Initially such capabilities will be used in a controlled manner in order to support equipment upgrades, bug-fixes etc. and will happen in a more or less static way. As regulation/type approval, security, safety and fault tolerance issues are resolved, re-configuration of the radio functionality will extend to enable switching between communication standards. This will necessitate re-configuration of the physical as well as the higher layers in the protocol stack. This new capability will enable/facilitate spectrum management, infrastructure resource allocation, global roaming etc. However such capabilities will necessitate to devise some globally accepted mechanisms in order to exchange re-configuration information between the involved entities. Doing so the network will get increasingly involved in order to perform and account for these changes.

As such capabilities and features will mature and will become current practice the next step will be to add more intelligence in the communicating re-configurable devices in order to make re-configuration more dynamic in nature, more transparent for the network and completely transparent for the user. Building on device capabilities to characterize their environments (e.g. user requirements-profiles, transmission conditions, device connectivity) the equipment could reason on how to adapt to it in the best way.

4 CONCLUSIONS

Given the worldwide activities relating to software and re-configurable radio research the results presented in this paper give an initial view of the potential application of SWR and current technology capabilities. The presented results concretely demonstrate that it is currently feasible to implement some kind of SWR with existing technology by extending digital, and especially software, processing to at least some IF. As component performances will further increase, higher IFs will be handled in the same way increasing thus system flexibility. For our research lab the presented work is just a first step towards the realization of the potential of SWR [4]. This first step covers only the SWR aspect dealing with software/ configurable implementations of different standards on generic hardware platforms. The important aspects of hardware/software design for re-configurability and re-configuration mechanisms are topics of future work. Technology and manufacturing constraints (size, power, cost etc.) make that RR will have a different deployment roadmap for each type of device so one of our objectives is to see how the RR technology will fit into different types of equipment, namely the terminal and the BTS.

5 ACKNOWLEDGMENTS

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