

Prototyping advanced 3G/4G wireless and SDR (Software Defined Radio) systems on the DSP/FPGA SignalMaster platform using a system-level approach.

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ABSTRACT :

This paper will describe the development and prototyping of SDR (Software Defined Radio) and advanced 3G/4G wireless systems on a hybrid DSP/FPGA platform using a system-level approach. The first part of the paper will briefly describe different development efforts and standards in wireless communication, both established and emerging. Then, the benefits of using an SDR approach and a reconfigurable platform to address these different standards will be presented, more specifically in the context of using a hybrid DSP/FPGA platform and system-level tools to prototype the SDR systems. Different application examples are given, ranging from 'basic' single-channel SDR to multi-channel smart (or array) antennas and space-time processing systems, WCDMA and OFDM modulation schemes such as in advanced and broader band 3G/4G systems. Implementation results and comparison with other development and technology implementation approaches are also given.

Categories and Subject Descriptors

DSP development tools and platform

General Terms

Algorithms, design experimentation

Keywords

SDR, DSP, FPGA, DSP platform, System-level tools,

1. INTRODUCTION

With the multiplicity of standards in cellular and wireless telephony, ranging from 'plain' AMPS (Analog cellular in the 800 MHz range), GSM (with 3 bands : 900, 1800 and 1900 MHz), Wireless LAN IEEE 802.11 a/b standards and upcoming 3G (third generation), array antennas and space-time systems, (not to mention Bluetooth !), developers are faced with many challenges. One of these challenges is to develop SDR devices

that can be reprogrammed to operate in multi-standard modes that address not only interoperability aspects, but interference problems as well. To this must be added the soon to be implemented higher bandwidth systems, the increase complexity of protocols, etc.. On a general basis, with the convergence of telecommunications and network devices, communication developers need to know such wide-ranging disciplines as data communications, RF, DSP, embedded programming, voice and data computing requirements and emerging standards in the next-generation (broadband) communication devices.

To give an idea of the numerous development efforts going on worldwide and to justify the use of the reconfigurable SDR approach, let's mention some of them (This is not an exhaustive listing of projects, but a representative subset). As we know, the different 3G approaches will coexist under the IMT-2000 (International Mobile Telecommunications 2000) umbrella, where both CDMA-2000 and W-CDMA standard will coexist. These two standards have their roots in the North American TDMA/CDMA approaches (IS-95) and European/Rest of the World (Japan excepted) GSM Standards. Considering that 'legacy' 1/2G systems also have to be supported, this gives already quite a number of standards.

Then comes into consideration the quest for higher bandwidths, and the accompanying more complex approaches such as MIMO (Multiple Input, Multiple Output) or multi-element antenna, such as shown in Figure 1. This technology is quite promising, and a number of European projects (I-METRA, SATURN, FLOWS [1]) are studying them. OFDM (Orthogonal Frequency Division Multiplex) is also a higher performance modulation approach; it is mostly used within the 802.11 Wireless LAN series of standards (those targeting higher bandwidths) but also considered for mobile voice network [2].

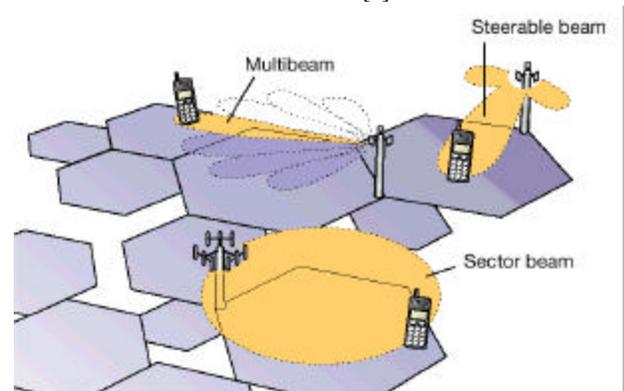


Figure 1: MIMO system allowing broader bandwidth using steerable beams

The quest for broader band and the merging (or collision?) of wireless data and voice networks has been integrated within the so-called 4G effort, where multi-standard and multi-service broadband sessions are rendered possible, such as in the Japanese MIRAI project [3].

The proliferation and parallel evolution of these different approaches and standards brings to forefront the utility of reconfigurable platforms or SDR platforms. In fact, a multitude of advanced european projects (CAST, PASTORA, TRUST STINGRAY [1]) are studying different aspects of SDR platforms.

It should also be considered that most of the standards have provisions for advanced and commercial differentiation features, which doesn't simplify the "universal base station" designer's life.

In the US, SDR research is pre-eminently lead by DoD. In a large effort to produce widely capable and adaptable systems, SDR efforts are centered in the SCA (Software Communication Architecture) under the JTRS (Joint Tactical Radio System) program [4]. A number of acquisition programs are already requesting the SCA approach (DMR, CAMP). Also, use of SDR's is considered for sophisticated airborne co-site cancellation systems, needed to address the time varying EMI effects from aircraft propellers[5].

All these consideration done, the need for flexible and reconfigurable systems appear clear.

2. USING SYSTEM-LEVEL TOOLS AND RAPID-PROTOTYPING

To address the challenge of designing such complex systems, the developers need tools that complement their expertise and address all these difficult interoperability and high performance issues at the simulation and verification level prior to and/or during implementation and testing phases. Design verification models can be expanded and synthesized for specific target hardware, using heterogeneous simulation and co-verification approaches. With an ever shortening time-to-market pace, development, integration and field verification phases have to be minimized as much as possible in order to reduce time consuming redesign steps.

Designing advanced broadband wireless systems is a tough challenge, mostly caused by the hostility of the wireless environments. A radio signal transmitted between a fixed base station and a moving vehicle in a typical urban environment exhibits extreme variation in both amplitude and apparent frequency. The various distortions of this environment have been well studied:

- Shadowing, caused by large reflectors and obstruction;
- Multipath fading, due to multiple propagation paths between the subscriber and the base, where copies of the signal reach the receiver where they add up either constructively or destructively according to their relative phase relationship;

- Doppler spread, produced by the combination of the well-known doppler effect caused by vehicle movement and the multiple copies of multi-path signals, which will spread the signal spectrum.
- Angular spread, representing the notion that in a real channel the signal is not a single discrete entity but is spread out more or less evenly within a certain angular region.

These different channel effects are implemented in channel models such as AWGN (Average White Gaussian Noise), Rayleigh, Rice, Nakagami and more complex ones used in MIMO testing such as GBSBEM, GBSBM, and GWCM [6] that provides time-varying statistical estimates of the direction of arrival (DOA) and Doppler spectrum.

The developer will then use simulation tools allowing modeling and simulating the transmission channel and implementation of the systems themselves. For example, one can use the widely use Matlab and Simulink tools to this extent (see Figure 2)

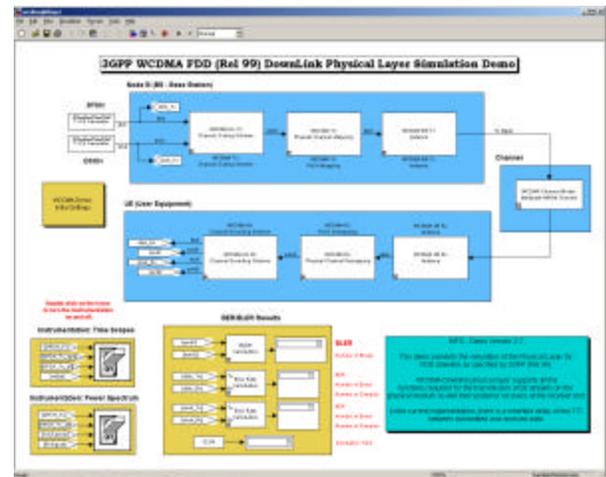


Figure 2: Typical Simulink model for a WCDMA system

The model shown in Figure 2 is a "classical" simulation model, where the "system" is simulated, including the channel. In this model, one can find a mix of simulation primitives for DSP functions and C-code functions (applications previously developed independently). From these classical simulation capabilities (which benefits are well known and appreciated from the development community), the possibilities to generate code for all or single components of the model can extend the simulation activity toward target implementation in an approach frequently referred to as rapid-prototyping. Of course, the code generated is not optimal but the gain in development speed is quite interesting.

In fact, this approach, sometimes referred to as system-level development, is very rich in term of implementation and testing capabilities. For example, the possibility to "target" toward final or intermediate hardware allows testing "in-system" of the target code from/within the system level simulation tool. Doing so, a previously implemented HDL code can be integrated in the design and simulation chain. When using a hybrid DSP/FPGA architecture such as on the Signal Master platform, the model

can be broken down in components for the DSP, the FPGA and the host [7].

The next step is to go further in the implementation sequence and take signal I/O related portions of the model, and have its related generated code running in real-time on target hardware. In a similar manner, a non-field system related component such as the channel model, for example, can also be segmented, hardware targeted and run in real time to test the final target hardware. The idea here is to provide some kind of “expertise continuum” between the simulation phase of a project and its final pre field-testing phase. Doing so, costly field constated errors can be identified and corrected previously to real field testing.

To summarize the use of a system-level simulation and implementation approach allows to :

- Co-simulate model components in the host computer and target hardware;
- Perform HIL (Hardware in the loop) specific component of the model;
- Execute in real-time specific model components, with system-level monitoring.

3. PARAMETER TUNING EXAMPLE CASES

Let’s consider the Raised Cosine pulse-shaping filter commonly used in software radio technology, as a typical example to show the usefulness of the system level approach. (See Figure 3). By controlling the filter’s roll-off factor β , the design can be optimized for less excess bandwidth (β closer to 0) or for less ISI (β closer to 1). The modulation scheme for each wireless standard mandates a different roll-off factor.

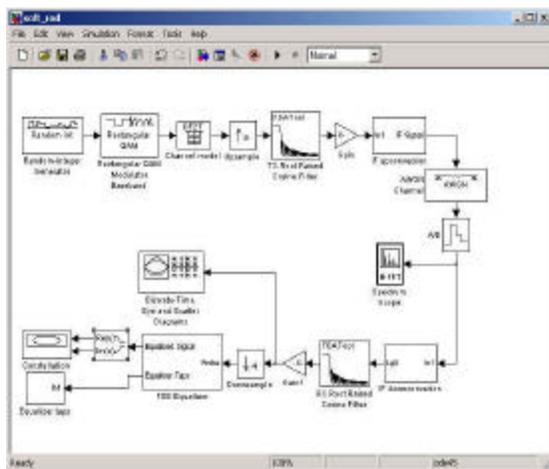


Figure 3: Simulink model for the transmitter and receiver chains of a software-defined radio including a Fractionally Spaced Equalizer to combat the ISI introduced by the channel [8].

In a multi-standard software radio, the pulse-shaping filter structure remains constant, the coefficients and the roll-off factor must be field-programmable. Similarly, the key parameters of other components need to be re-programmed to

meet the specifications of each supported standard and to handle variations in operating conditions.

The systematic experimentation required to vary the β values and determine the accompanying effects on other system components can be time consuming with traditional methods and implementation-oriented languages. Implementation languages lack the interactive simulation, analysis, and visualization capabilities required to rapidly iterate the design based of parameters such as the pulse-shaping filter response.

In the multi element antennas case such as in Figure 4, one can imagine that the need to use system-level exploratory tuning of parameters is increased by an order of magnitude, where time equalizers such as RAKE filters are combined to space equalizers to augment the SIR (Signal to Interference Ratio).

Example of empirical parameters are :

- Window type used to perform DFT on the PSD of the correlation matrixes, in the context of DOA estimation (MUSIC, ESPRIT, SAGE algorithms).
- Overall gain of the weights used to combine the array element data
- Geometrically related parameters in the context of multiple complex antenna patterns.

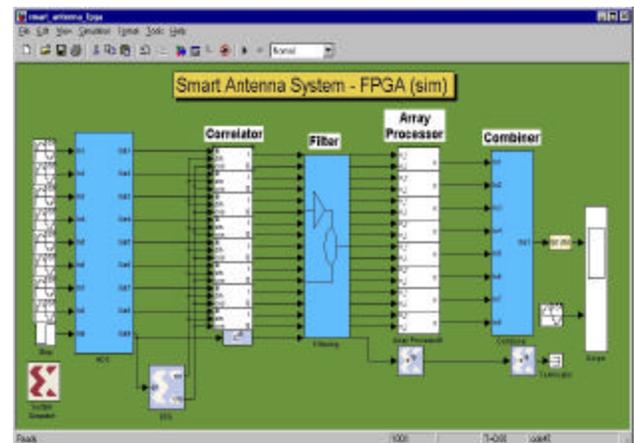


Figure 4: Simulink model for an FPGA-based beamformer of a MIMO system.

4. SOME RESULTS AND BENCHMARKS

Automatic code generation from system-level tool will always be less efficient than manually crafted and designed DSP or VHDL code, although system level tool vendors are aiming to narrow quite a lot this gap. The advantages of using system level tools have to be balanced with the performance cost. Nonetheless, for signal processing applications, they provide an almost necessary approach to test all application conditions.

A tendency in “system-level development”, in order to compensate for the inefficiency of “generic” automatic code generation with respect to manually coded applications (either at the C or assembly levels), is to combine the use of C-code based simulation with optimised libraries or cores substituted when building the target application. Such an approach is best

exemplified in the Xilinx System Generator extension to Simulink. In this case, “target specific” structural VHDL is generated, as a compromise to “pure” system level code. A similar approach is done even with DSP targeted code. In figure 5, we see a comparison of FPGA and DSP code generated “at the system level” including the overhead generated by the approach (estimated at 25 %). Standard approaches, implemented using discrete IC’s and DSP’s are mentioned for comparison .

If we look at Figure 5, we can see that the ratio of cost of implementation on a system-level reprogrammable platform vs the classical approach is not that high, (and will continue to decline in the coming years). If we could compare the cost of NRE, then the ratio would be totally inverse, and would most likely augment in the coming years, considering that system-level tools will become more and more effective. If we would evaluate the development costs of developing classically a MIMO application, one could calculate that they would be quite formidable; maybe enough to conclude that it is not a viable alternative. Still, one has to remember that developing such products with a system level approach will never be a “push button” thing. Skilled engineers will always be needed to render effective the systems developed, more specifically the FPGA component.

IP Core /Library	Total resources (# FPGA slices/ DSP MIPS)	Total resources (%) Virtex XCIV-1000/C6203	Cost	Alternative Cost Discrete IC’s	
				(Gates/ MIPS)	\$\$\$
DDC	900 slices	30 %	80\$	15,000 Gates	25\$
DDS	375 slices	12 %	25\$	1500 Gates	10\$
FFT	1125 slices	37 %	100\$	19000 Gates	32\$
AWGN model	600 slices	21 %	55 \$	N/A	N/A
G.729	10 MIPS	6%	4\$	7.5 MIPS	3 \$

Figure 5:Implementation results in typical FPGA’s and DSP’s assuming 25% overhead for system-level development

We then come to a complex balancing of development cost, schedule, cost of platform and final product. There is no clear case, and effectively advantageous use of a system level approach will depend on the application. In the MIMO case, and considering the complexity of the application and its remote time before commercial field implementation (in the context of ever declining cost of programmable gates), the combination of DSP, FPGA and system-level tool seems quite appropriate.

5. CONCLUSION

This paper has presented an approach for using high-level tools to simulate and implement state-of-the-art wireless applications. It also presented a platform that eases the development of an optimised target from these high-level tools. Some benchmarks are also presented, giving indications on the validity and

effectiveness of the overall approach. Depending of the application, system-level approach will become more and more effective in the coming years, considering the evolution of methodologies and programmable logic parts.

REFERENCES

- [1] Fabrizio Sestini, Jaoa Schwarz da Silva, and Jose Fernandes, «Expanding the Wireless universe : EU Research on the Move», IEEE Communications Magazine, October 2002
- [2] Gang We and Mitsuhiro Mizuno, Communications Research Laboratory, Japan, Paul J.M. Havinga, University of Twente, the Netherlands, “MIRAI Architecture for Heterogeneous Network”, IEEE Communications Magazine, February 2002.
- [3] OFDM for Mobile Data Communications, Flarion, 2002.
- [4] “JTRS SCA”, [Http://www.jtrs.saalt.army.mil/](http://www.jtrs.saalt.army.mil/), Joint Tactical Radio System Joint Program Office
- [5] David K Murotake, Ph.D., SCA Technica Inc., “Use of switched fabrics in implementation of software defined radio smart antenna and interference cancellation signal processing. ”, SDR’02 Conference, San Diego, November 2002.
- [6] Per Steve Gifford, John E. Kleider and Scott Chuprun, General Dynamics, Decision Systems, “A flexible geometric wide-band time-varying channel model for V-Blast MIMO simulations”, SDR’02 Conference , San Diego, November 2002.
- [7] Louis Belanger, LYR Signal Processing, John Ahern, Comlab, Paul Fortier, Electrical and Computer Engineering Dept. Laval University, “Prototyping wireless base stations or edge devices on a DSP/FPGA architecture using high-level tools”, ICSPAT Conference, Dallas, November 2000
- [8] 802.11a & WCDMA Wireless Communication System Design with MATLAB and Simulink. The MathWorks Inc. 2002.

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