



Conceptual Design of MIMO Wireless Communication System

Pooja S. Suratia¹, Satish K. Shah²

Department of Electrical Engineering, The Maharaja Sayajirao University of Baroda.^{1,2}

poojasuratia@yahoo.com¹, satishkshah_2005@yahoo.com²

ABSTRACT— *Next-generation communication evolution towards 4G promises to meet the demands for ubiquitous communication. MIMO technology has become a mandatory requirement to achieve the goals of future wireless communication. This paper describes the System design methodology for MIMO Wireless platform. Software simulations provide flexibility, but the true performance of the system can only be known by developing a hardware wireless platform and performing measurements and tests in the target environment. Hardware Implementation concept of MIMO Wireless platform based on DSP and FPGA is presented, various development tools available for system simulation and analysis is discussed. This paper gives an overview of Conceptual System Design Methodology, Software simulation tools and hardware implementation strategy for developing MIMO Wireless Communication System.*

Keywords - 4G, MIMO, DSP and FPGA.

I. INTRODUCTION

The ever-growing demands for high-speed data and multimedia services are the driving forces behind the requirements for future wireless communication systems. The next generation of mobile communication, often referred to as 4G (Fourth Generation) networks are comprehensive IP solutions that deliver voice, data, and multimedia content to mobile users anytime and almost anywhere [1]. LTE (Long Term Evolution) is a global 4G standard [19]. Wireless communication is inherently limited by the available spectrum and impaired by path loss, interference and multi-path propagation. Hence, to meet the capacity needs for future wireless systems without increasing the required spectrum, accomplishment of implementation of advanced communication techniques is necessary. MIMO (Multi-input multi-output) promises high bit rates, small error rates, reliability, increased channel capacity over rich scattering wireless channels without consuming extra bandwidth or transmit power when compared to conventional single antenna technologies [5]. MIMO techniques are heavily exploited and integrated into many wireless standards like third-generation (3G) and fourth-generation (4G) wireless communication systems [2], IEEE 802.11n wireless local area network (WLAN) standard [10], IEEE 802.20 mobile broadband wireless access system [6] and the 3GPP Long Term Evolution (LTE) of wideband CDMA (W-CDMA) [13].

To meet the demand for ubiquitous communication and the ability to access and share information, wireless appliances and the supporting networking infrastructure must be

equipped with adequate computing and signal processing capabilities. Recently, various MIMO wireless testbed based on DSP (Digital Signal Processor) and FPGA (Field Programmable Gate Array) have been developed to verify the theoretical performance gains and to investigate practical issues in MIMO implementation. These systems are realized by computationally complex algorithms, requiring new digital hardware architectures to be developed.

This paper discusses the conceptual design of MIMO wireless communication system. Section II describes the Design methodology for MIMO system and relevant decisions. Section III discusses the software tools for analysis and DSP/FPGA implementation issues. Section IV discusses the basic hardware concept of MIMO Communication System, followed by Summary and Conclusion in Section V.

II. SYSTEM DESIGN METHODOLOGY

Next-generation communication systems promise to deliver a wide variety of new features, such as improved battery life, high-definition video and high-bandwidth Internet connections. In designing of such systems, the development and integration of several computationally-intensive algorithms which enable these new features are to be incorporated. Software simulations provide more flexibility, but the true performance of the system can only be known by developing a hardware wireless platform and performing measurements and tests in the target environment. In spite of their performance enhancing capabilities, most of the research on MIMO technology up

to the moment is based on theoretical studies. The most popular methodology for testbed development is rapid prototyping [3,7,8,11]. In this approach, to develop real-time algorithms on testbed, first the simulation implementation is done. Next, the simulation is migrated to the testbed and, finally real-time implementation is obtained. The speed and complexity of MIMO-based system requires comprehensive design and verification process including both hardware and software. Experiments in real-world scenarios by means of hardware implementations are necessary to measure the actual performance of system. Figure 1 describes the System Design Methodology for MIMO Wireless Platform. The scope of this design methodology extends from specification to implementation. According to Functional Description/ Specifications various system modelling tools, software tools and hardware platform is selected. For designing MIMO Wireless Platform various design specifications are considered such as, environment (indoor/outdoor), wireless standard, carrier frequency, bandwidth, sampling frequency, measurement device, real-time/off-line, number of transmitter and receiver antennas, with or without feedback, single or multiple users, type of modulation, achievable data rate [18].

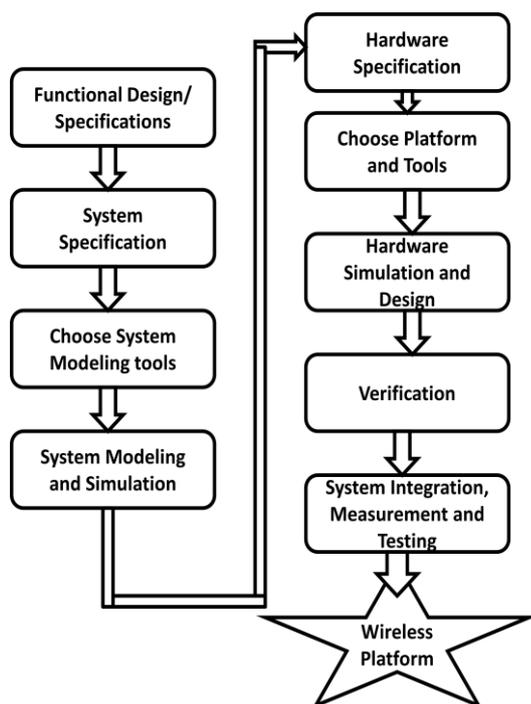


Figure 1. System Design Methodology for MIMO Wireless Platform

Based on the system specifications, system modeling is done using simulation tools like MATLAB Simulink simulation analysis. Once the system is analysed in Simulink, the hardware simulation and verification is carried out and finally the integration, measurement and testing is done. Rapid Application Development (RAD) tools for fast prototyping are getting very popular, because they are promising reduced learning time and project time. RAD tools give also the possibility of hardware and software co-design by putting simulation in software and real hardware together.

III. SOFTWARE SIMULATION TOOLS FOR DSP AND FPGA

This section discusses the software simulation tools for DSP and FPGA. Many rapid prototyping platforms are available such as DSPs (TI's C6x), FPGAs (Xilinx), or mixtures of DSPs and FPGAs. Various software simulation tools are provided by the manufacturer to ease the development of communication system. These tools can be integrated with MATLAB Simulink to provide a path from block diagram to system integration such as Xilinx System Generator and Link to CCS/Real-time workshop as shown in Figure 2.

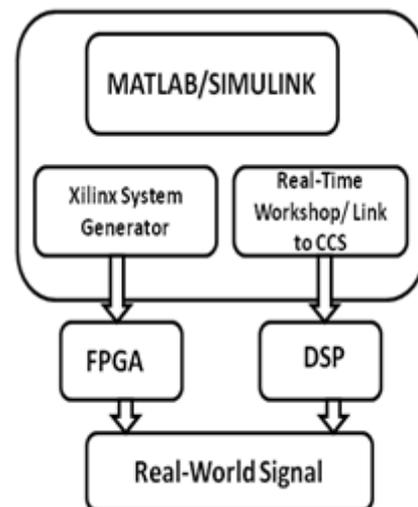


Figure 2. Design Flow for Software Simulation

For DSP-based development, TI's Code Composer Studio (CCS) for the C6000 family of TI's DSPs gives all tools needed for developing, analysis, and debugging DSP algorithms in an integrated development environment (IDE). Mathworks offers with Simulink and the Real-Time Workshop (RTW) a seamless RAD tool for fast prototyping in DSP based systems. This approach also offers the possibility of hardware-in-the-loop simulation, where parts



of the application may run on the target DSP and others run on the PC. Other methodologies, such as The Mathworks Real-Time Workshop in combination with the Embedded Target for the TI TMS320C6000 DSP Platform allow mapping a Simulink block diagram composed of pre-existing algorithm blocks to a single DSP.

Table I. MATHWORKS Products for Wireless And Embedded Systems

Modeling Wireless Systems	Implementing Embedded Systems
<p>Core products for signal processing</p> <ul style="list-style-type: none"> • Simulink, • Signal Processing Blockset, • Simulink Fixed Point, • Simulink Accelerator, • Signal Processing Toolbox, • Fixed-Point Toolbox <p>Modeling products for wireless applications</p> <ul style="list-style-type: none"> • Communications Blockset, • RF Blockset, • Communications Toolbox, • RF Toolbox, • Filter Design Toolbox, • SimEvents, • Stateflow, • SimPowerSystems 	<p>Embedded C Code Generation and Verification</p> <ul style="list-style-type: none"> • Link for Code Composer Studio, • Real-Time Workshop, • Real-Time Workshop Embedded Coder, • Embedded Target for TI C6000 DSP, • Stateflow Coder <p>HDL Generation and Verification</p> <ul style="list-style-type: none"> • Link for ModelSim, • Filter Design HDL Coder • Synplify DSP (Synplicity) • Xilinx System Generator for DSP™ • DSP Builder (Altera)

For FPGA development, several design suites are available. Targeting at Xilinx's Virtex-II family, three major players are well-known: Xilinx Corporation with its Integrated Software Environment (ISE), Mentor Graphics Corporation with its FPGA advantage suite and Synplicity Inc. with its synthesis and verification solutions. Typically, they all support up to three most common hardware description languages (HDLs): VHDL, Verilog, and Advanced Boolean Equation language (ABEL). VHDL stands for VHSIC (very high speed integrated circuit) hardware description language. For DSP-based signal processing, Simulink block diagrams can also be mapped onto FPGAs using the Xilinx System Generator Blockset and software in combination with hardware. Table I lists the Mathworks Products available for

Software simulation for modeling Wireless Systems and Implementation of Embedded Systems.

IV. HARDWARE IMPLEMENTATION ISSUES

Various MIMO Wireless testbed [9,12,14-16] have been developed to evaluate a particular standard or specification while others have been designed for general purpose. There are different hardware platforms for implementing high performance algorithms for MIMO Wireless system. Following categories of platforms can be identified:

- i) General purpose processors (GPP),
- ii) Digital signal processors (DSPs),
- iii) Field programmable gate arrays (FPGAs),
- iv) Application specific integrated circuits (ASICs),

Hardware implementation of the wireless system can be achieved using general-purpose processors, but it faces difficulties when dealing with high processing systems. FPGA is suitable for fast implementation, quick hardware verification and is reprogrammable, whereas ASIC is designed for a particular application. DSPs are suitable for complex computation DSP signal processing algorithms. The integration of powerful FPGAs and DSPs is feasible for testing MIMO algorithms for real-time systems. DSPs provide a specialized core with multiple-functional units, which are optimized for digital signal processing operations like filtering and transformations. FPGA has the ability to provide special hardware structures in parallel, and to handle high data rates without affecting other algorithms. It is also convenient to split the real-time implementation into several steps: firstly, a fixed-point code is implemented on DSP and, afterwards, the software modules that do not meet time requirements are migrated to FPGA [4,17]. Figure 3 shows the Basic Hardware Architecture of MIMO Communication System. It consists of two units: Analog RF Unit (RF) and Baseband Processing Unit (BB). The first stage consists of the RF modules mixing the signals of each antenna from RF to BB following the receiver path, the next stage consists of the Analog-to-digital converter (ADC) and Digital-to-analog converter (DAC). The succeeding FPGA stage allows high-speed parallel data processing for various processing tasks. Therefore, the FPGA stage covers the complete MIMO front end, i.e. antenna filtering operations, the synchronization of time and frequency, the signal modulation and demodulation, and all other regular processing operations. The FPGA operates on the incoming high-data-rate digital signal and reduces the data-rate stepwise. In the DSP stage, all less regular MIMO processing takes place, i.e. algorithms which are under study. Among the hardware platform and its components, a rich set of software tools is required to

develop DSP- and/or FPGA-based applications in an efficient and fast way.

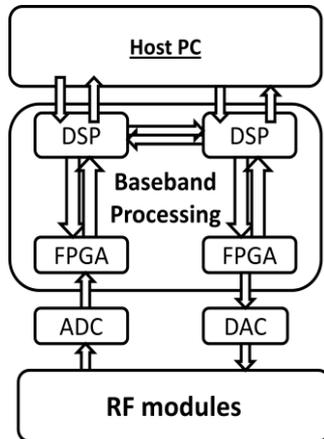


Figure 3. Basic Hardware concept of MIMO Communication System

Lyrtech offers a testbed formed by base-band modules integrated in a PC plus a Quad Dual-Band RF transceiver that allows building a dual-band MIMO 4 x 4 system at both 2.4 and 5 GHz bands [20] as shown in Figure 4.

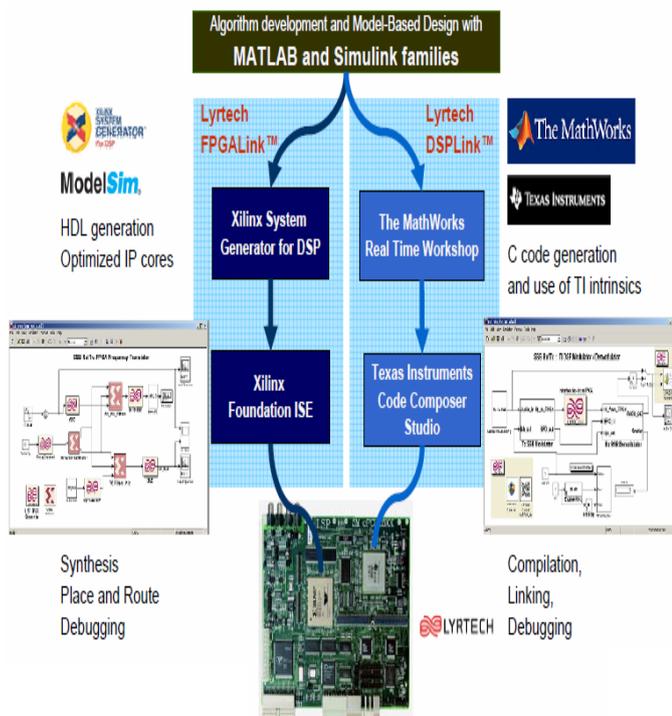


Figure 4. Tools for Demo Hosted from PC [20]

V. CONCLUSION

This paper discusses in detail the System Design methodology for MIMO Wireless Communication. It also discusses various Software development tools available for Software Simulation on DSP and FPGA. Basic Hardware Concept for MIMO System is discussed which consists of mixture of FPGA and DSP. MATLAB Simulink based modeling of MIMO wireless System can be done and then software simulation can be carried out using Rapid integration tools for DSP/FPGA. Finally, a wireless platform developed can be used for measurement and testing purposes. Due to reprogrammability feature of FPGA, different algorithm can be studied in detail and verified. As DSP is suitable for highly complex computation of DSP signal processing, it can be used for analysis of complex algorithms. The Wireless platform developed can be used by researchers to carry out research and develop new algorithms and to verify results for better performance of the system.

ACKNOWLEDGEMENT

The project is sponsored by Department of Science and Technology (DST), Government of India, under the Women Scientist (WOS-A) Scheme.

REFERENCES

- [1] B. G. Evans and K. Baughan, "Visions of 4G," Electronics and Communication Engineering Journal, Dec.2002.
- [2] R. T. Derryberry, S. D. Gray, D. M. Ionescu, G. Mandyam, and B. Raghathan, "Transmit diversity in 3G CDMA systems," IEEE Commun. Mag., vol. 40, no. 4, pp. 68–75, Apr. 2002.
- [3] A. Adjoudani, E. Beck, A. Burg, G. M. Djuknic, T. Gvoth, D. Haessig, S. Manji, M. Milbrodt, M. Rupp, D. Samardzija, A. Siegel, T. S. II, C. Tran, S. Walker, S. A. Wilkus, and P. Wolniansky, "Prototype Experience for MIMO BLAST over Third-Generation Wireless System", Special Issue JSAC on MIMO Systems, vol. 21, pp. 440–451, Apr. 2003.
- [4] P. Murphy, F. Lou, A. Sabharwal, J.P. Frantz, "An FPGA based rapid prototyping platform for MIMO systems", Proc. of Asilomar, vol. 1, pp. 900–904, Nov. 2003.
- [5] A. J. Paulraj, D. A. Gore, R. U. Nabar, and H. Boelcskei, "An overview of MIMO communications -A key to gigabit wireless," Proc. IEEE, vol. 92, no. 2, pp. 198–218, Feb. 2004.
- [6] "System requirements for IEEE 802.20 mobile broadband wireless access systems," IEEE, Draft IEEE 802.20-PD-06 version 14, July 2004.
- [7] T. Kaiser, A. Wilcek, M. Berentsen, and M. Rupp, "Prototyping for MIMO Systems - An Overview", in Proc. of the 12th European Signal Processing Conference (EUSIPCO), pp. 681–688, Vienna, Austria, Sept. 2004.
- [8] P. Belanovic, B. Knerr, M. Holzer, G. Sauzon, and M. Rupp, "A Consistent Design Methodology for Wireless Embedded Systems", EURASIP Journal on Applied Signal Processing, vol. 16, pp. 2598–2612, Oct 2005.



- [9] R. Mysore Rao, W. Zhu, S. Lang et al, "Multi-Antenna Testbeds for Research and Education in Wireless Communications", IEEE Communications Magazine, pp. 72–81, Dec.2004.
- [10] Y. Xiao, "IEEE 802.11n: Enhancements for higher throughput in wireless LANs," IEEE Wireless Commun., vol. 12, no. 6, pp. 82–91, Dec. 2005.
- [11] C. Mehlh'uhner, F. Kaltenberger, M. Rupp, and G. Humer, "A Scalable Rapid Prototyping System for Real- Time MIMO OFDM Transmissions", in Proc. of the 2nd IEE/EURASIP Conference on DSP enabled Radio, Southampton, UK, Sept. 2005.
- [12] A. G. Fabregas, M. Guillaud, G. Caire et al, "A MIMO- OFDM Testbed for Wireless Local Area Networks", Proc. of Asilomar, pp. 82–86, Nov. 2005.
- [13] H. Ekstroem, A. Furuskaer, J. Karlsson, M. Meyer, S. Parkvall, J. Torsner, and M. Wahlqvist, "Technical solutions for the 3G Long Term Evolution," IEEE Commun. Mag., vol. 44, no. 3, pp. 38–45, Mar. 2006.
- [14] D. Ramirez, I. Santamar'ia, et al, "A flexible testbed for rapid prototyping of MIMO baseband modules", ISWCS 2006, Valencia, Spain, Sept. 2006.
- [15] M. Rupp, C. Mehlh'uhner, S. Caban, R. Langwieser, L. W. Mayer, and L. Scholtz, "Testbeds and rapid prototyping in wireless system design", EURASIP Newsletter, vol. 17, no. 3, pp. 32–50, Sep. 2006.
- [16] S. Caban, C. Mehlh'uhner, R. Langwieser, A. L. Scholtz, and M. Rupp, "Vienna MIMO Testbed", EURASIP Journal on Applied Signal Processing, vol. 2006, Article ID 54868, 2006.
- [17] S. Roy, L. B'elanger, "The Design of an FPGA-Based MIMO Transceiver for Wi-Fi", Xilinx DSP Magazine, May 2006.
- [18] M. Rupp, S. Caban, C. Mehlh'uhner, "Challenges in Building MIMO Testbeds", European Signal Processing Conference, Poland, Sept. 2007.
- [19] D. Ast'ely, E. Dahlman, A. Furusk'ar, Y. Jading, M. Lindstr'om, S. Parkvall, "LTE: the evolution of mobile broadband", IEEE Communication Magazine, April, 2009.
- [20] Mika Vaittinen, "Developing Wireless Systems with MATLAB and Simulink", www.mathworks.com/wbnr30424



Satish.K.Shah is Head of Department of Electrical Engineering, Faculty of Technology and Engineering, The Maharaja Sayajirao University of Baroda, Vadodara, Gujarat, India with 30+ years of teaching and research experience. His current areas of interest include Wireless Communication, Control, Soft-computing and Embedded Controllers. He has presented 20+ research papers in national & international conferences and published 10+ research papers in technical journals.

BIOGRAPHY



Pooja S. Suratia is currently a Research Scholar in Department of Electrical Engineering, Faculty of Technology and Engineering, The Maharaja Sayajirao University of Baroda, Vadodara, Gujarat, India. She received Masters of Engineering Degree in Automatic Control and Robotics from The Maharaja Sayajirao University of Baroda (2009) and a Bachelor of Engineering in Electronics and Communication from Sa'd Vidya Mandal Institute of Technology, Bharuch, Gujarat (2006). Her current research interests focus on MIMO Wireless Communication and Optimization of future wireless systems.