

FPGA Implementation of Beamforming Receivers Based on MRC and NC-LMS for DS-CDMA System

Elie H. Sarraf, Messaoud Ahmed-Ouamir, and Daniel Masicotte

Department of Electrical and Computer Engineering, Université du Québec à Trois-Rivières
Québec, Canada. Email: {elie.sarraf, messaoud.ouamir, daniel.masicotte}@uqtr.ca, www.uqtr.ca/ee

Abstract—In this paper, we investigate a beamforming receivers based on maximum ratio combining (MRC) and noise constrained least mean square (NC-LMS) using rapid prototyping method for FPGA implementation. Non-adaptive and adaptive beamforming techniques approaches are considered. A performance evaluation of these algorithms in a DS-CDMA system is presented and FPGA design is evaluated in terms of hardware resources for Xilinx family devices using rapid prototyping methodology with Matlab-Simulink tools. Both approaches offer a good performance-complexity tradeoff favorable for FPGA implementation. However, due to the adaptive approach, the NC-LMS presents a better robustness to the fixed point arithmetic than the MRC.

1. INTRODUCTION

THE need, the quest for high-performance, high-speed, high-quality, high-reliability and most importantly low-cost systems drives the engineers to different and unlimited frontiers of design and implementations. In this paper we face the problem of Beamforming or Smart Antennas (SA) design and implementation for DS-CDMA systems equipped with multiple receiving antennas.

SAs are recognized as a key technology for capacity increase in 3G radio networks. A SA's ability to abate both multipath and co-channel interference makes it one of the leading candidates [1] and one of the most promising technologies for the enabling of high capacity of the wireless networks, and interference cancellation. The most important contributions of an SA is its capability of changing its pattern in real time in order to track the user of interest with its maximum gain while trying to minimize the interference by placing the nulls of its radiation pattern at locations of the other users [2], i.e. the interferers.

Beamforming is the complex mathematical process standing behind that behavior of the antenna or the base station. We describe it as the backbone of the SA, or the main core of it. The beamforming is a process in which each user's signal is multiplied with appropriate weights that adjust the magnitude and the phase of the signal from each antenna. Hence the array forms a transmit beam in the desired direction and minimizes the output in other directions.

Considering the hardware implementation for beamforming algorithms, few past works have been reported. In [3], a reduced sampling rate beamforming technique for the reception of acoustic data transmitted through the water has been implemented on a DSP from Texas Instrument. In [4], the authors present an FPGA

implementation using Xilinx devices and calibration methodologies for a smart antenna digital beamforming consisting of eight channels and operating in L band (1.8 to 2GHz). A comparison of efficient broadband beamforming architectures is presented in [5]; however no comparison on hardware resource is reported. A low power ASIC implementation of 2Mbps antenna-rake combiner supporting both maximum ratio combining (MRC) and least mean square (LMS) filter is presented in [7] where a 107 Mhz clock frequency and 55mW as highest rate power are achieved. In this paper, we implement both MRC and noise constrained LMS (NC-LMS) based beamforming techniques on FPGA, using rapid prototyping techniques (Matlab-Simulink). We evaluate the performance and hardware resource for both techniques.

This paper is organized as follows. A signal model is briefly described in Section 2. Beamforming techniques and performance evaluation using MRC and NC-LMS is presented in Section 3. The FPGA implementation and results of the beamforming techniques are described in Section 4. A conclusion is presented in Section 5.

2. SIGNAL MODEL

Consider a reverse link from K mobile stations to a base station with multiple antennas. Let T represents the symbol interval; $s_{i,j}[n] \in S$ (S is the symbol alphabet; $S = \{\pm 1\}$ for binary phase shift keying (BPSK) case and $S = \{\pm \sqrt{2} \pm j/\sqrt{2}\}$ for quadrature phase shift keying (QPSK) case) the n th symbol and $d_{i,j}(r,n)$ the spreading waveform at the n th symbol of the i th transmission. The spreading waveform is written as

$$d_{i,j}(r,n) = \sum_{m=0}^{N-1} c_{i,j}[m] p(r - mT_c) \quad \text{where } T_c \text{ is the chip interval; } N = T/T_c \text{ the processing gain; } c_{i,j}[r,n] \text{ the } r\text{th}$$

element of the spreading sequence for the n th symbol of the i th transmission; and $p(r)$ is the chip waveform of unit energy. Assume that the base station is equipped with L antenna elements and $\mathbf{a}(\theta)$ denotes the array response vector to the signal with angle of arrival (AOA) θ . The channel vector $\mathbf{h}_{i,j}$ can be written as $\mathbf{h}_{i,j} \propto \cos(\theta)$. For Rayleigh fading channels or would be a complex Gaussian random variable. For M multipaths, there would be M spatial

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Digital Front-End in Wireless Communications and Broadcasting Fa-Long Luo, 2011-09-29 Covering everything from signal processing algorithms to integrated circuit design this complete guide to digital front end is invaluable for professional engineers and researchers in the fields of signal processing wireless communication and circuit design Showing how theory is translated into practical technology it covers all the relevant standards and gives readers the ideal design methodology to manage a rapidly increasing range of applications Step by step information for designing practical systems is provided with a systematic presentation of theory principles algorithms standards and implementation Design trade offs are also included as are practical implementation examples from real world systems A broad range of topics is covered including digital pre distortion DPD digital up conversion DUC digital down conversion DDC and DC offset calibration Other important areas discussed are peak to average power ratio PAPR reduction crest factor reduction CFR pulse shaping image rejection digital mixing delay gain imbalance compensation error correction noise shaping numerical controlled oscillator NCO and various diversity methods

Design of Multi-Beam Hybrid Digital Beamforming Receivers Suresh Madishetty, 2018 This thesis discusses a detailed study of the design and performance analysis of patch antenna arrays at different frequencies A linear hybrid array of 16 elements is built using patch antennas integrated with an RF front end using commercial off the shelf COTS components A well organized receiver chain that can work at a frequency in the range of 5.6 GHz is built using chip level components on a printed circuit board PCB This study mainly emphasizes the design and implementation of the comprehensive receiver beamforming systems using fast Fourier transform FFT algorithm

and approximate discrete Fourier transform a DFT 1 A low complexity 32 beam multi beamformer at 5.8 GHz is designed built and implemented in real time using optimized digital FPGA cores as the digital back end which is collaborated work with Viduneth Ariyaratna The emanating beams were measured and verified using the FPGA based 32 element 5.8 GHz array setup which can generate 120 MHz bandwidth per channel The beams corresponding to the approximate DFT are in good agreement with the beams corresponding to the FFT with negligible error approximately less than 14 dB This setup can be used as a test bed to measure and evaluate various signal processing algorithms up to 32 linear array elements **FPGA**

Implementation of Beamforming and OFDMA for WiMAX System, 2008 **Wave-digital Filter Based Circuits for Beamforming and RF-FPGAs** Nilanka Thilina Rajapaksha, 2015 Selective spatial filtering of propagating plane waves based on their direction of arrival is termed as beamforming Ultra wideband beamforming is an essential signal processing step in many real world applications such as wireless communications radar radio astronomy and biomedical imaging The radio frequency field programmable gate array RF FPGA is a conceptual device envisioned by the Defense Advanced Research Projects Agency DARPA research community to bring reconfigurable implementation ability to the RF analog domain Research on RF FPGA is important for the advancement of areas such as cognitive radio enhanced access to radio spectrum software defined radio and multi protocol communications This work explores analog and digital circuits based on the wave digital filter WDF realization structure that are suitable for digital analog beamforming applications and implementation of active filters on the conceptual RF FPGA device Digital infinite impulse response IIR 2 D and 3 D WDF beamforming architectures are capable of broadband beamforming with having low side lobe level array factors and lower arithmetic complexity Wave digital filter architectures having fan cone shape in the spatio temporal frequency domain are able to achieve approximately frequency independent beam patterns The IIR WDF architectures are proposed and implemented that are able to achieve a hexagonal cross section in the magnitude response which enables better packing density of sky area in certain applications The digital IIR WDF architectures are tested on chip using and FPGA based platform Resource consumption and operational frequency estimates from FPGA and standard cell application specific integrated circuit ASIC compilations are presented The superior sensitivity properties of the multi dimensional WDF architectures are demonstrated through simulation results A novel fixed point design method that eliminates overflow is introduced that can be utilized for all multi dimensional systolic array filter architectures Novel spatially discrete time continuous beamforming architectures based on the WDF realization are also introduced The same idea is proposed to be implemented for one dimensional filter realization which can be used as a reconfigurable filter realization platform for RF FPGA devices Preliminary Simulation Program with Integrated Circuit Emphasis SPICE level simulations have verified the feasibility of a modular analog building block that can be utilized to implement more complex circuits in a future effort *FPGA-based Implementation of a Digital Processor for an Instantaneous Frequency Measurement Receiver* James M. Helton, 2007 Digital wideband receivers are

essential elements used in electronic warfare EW applications Instantaneous Frequency Measurement IFM receivers are suitable for use in EW systems due to the ultrawide instantaneous radio frequency RF bandwidth fine frequency resolution and moderately high sensitivity and dynamic range Conventional IFM receivers use analog components such as power dividers crystal video detectors and hybrids This research presents the architecture and design implementation of a purely digital IFM receiver based on a patented algorithm courtesy of the United States Air Force The invention is capable of detecting a short wave pulse with 1 MHz error for every 100 nsec The benefits include a compact lightweight cost effective alternative to its analog counterpart The design was implemented and tested on Delphi s ADC3255 a PMC digitizer with Xilinx Virtex 4 FPGA The outputs were verified using Xilinx s ChipScope Pro FPGA Implementation for Complete Digital Quadrature AM Receiver Yan Wan,2004 **Implementation of a WCDMA AAA Receiver on an FPGA Based Software Radio Platform** Saju P. Kora,2001 **FPGA Implementation of Baseband Receiver for HIPERMAN System** ,2007 FPGA Implementation of Rajendra Kumar's Adaptive Receiver for Higher Order Modulated Signal Over Fading Channel Falgun Bhagavatula,2016 This project efficiently implements Rajendra Kumar Adaptive Receiver on FPGA with reduced number of gates Very High Speed Integrated Circuit Hardware Description Language VHDL codes and Xilinx ISE are used for replicating the adaptive receiver circuit on Nexys 3 Spartan 6 FPGA trainer board

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