High Data Rate Wireless Communication Test bed Frameworks - Insights into Design Aspects

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Abstract- With the explosive expansion of wireless communication and its continuously evolving systems, design of emerging solutions require appropriate mechanisms of testing, validation and verification. In this respect, a frequently adopted option is design of test beds to validate algorithms and implementation aspects. Some of the currently available test beds have evolved into reliable platforms of design formulation and validation. Here, we provide certain insights into the design of test beds related to high data rate wireless systems with focus on multi input multi output (MIMO) based systems. We review some of the relevant details of a few known designs and outline certain issues and challenges related to design of test beds that serve as proof of concept platforms for emerging technologies.

Keywords- DSP, FPGA, MIMO, MU-MIMO, LTE, Wireless

1. INTRODUCTION
Wireless communication has transformed the process of telephony with ever increasing reach and quality to a level that the present systems enable transmission of rich multimedia content worldwide anytime, anywhere. With the currently deployed 4-G systems, communication and computation have established a symbiotic association and are inseparable elements. During the last few decades, technologies related to wireless communication have been driven by innovation. The present wireless domain is infested by the ever expanding use of the industrial, scientific, and medical (ISM)-bands between 902- 928 MHz, 2.4 and 2.5 GHz and between 5.725 and 5.875 GHz and different standards of the IEEE 802.11 a/b/g/n etc preferred by wireless local area networks (WLAN) and Wi-Fi transceivers. Cellular networks have now become objects of common place with technologies such as Global System for Mobile Communications (GSM), code division multi access (CDMA) and general packet radio service (GPRS), to 3G networks such as wideband CDMA (W-CDMA), enhanced data rates for GSM evolution (EDGE) or CDMA2000 requiring constantly changing communication practices. The IEEE 802.11n with multi input multi output (MIMO) technology has further accelerated the growth of wireless systems with higher bandwidth and data rates. Orthogonal frequency division multiplexing (OFDM) is a spectrum efficient modulation method that has been accepted as a candidate to mitigate ill effects of fading thereby raising levels of quality of service (QoS) and preserving bandwidth. The combinations of MIMO-OFDM blends the advantages of both the schemes and has raised bandwidth utilization, QoS and have become the backbone of current and upcoming mobile networks [1]. With the adoption of MIMO, OFDM or the combination of MIMO-OFDM, receiver design complexities have increased tremendously. Computational complexity grows exponentially with number of transmit-receive (Tx-Rx) pairs added in MIMO systems. Further, complexities especially in designs are observed with systems configured using optimum error rate performance algorithms like the maximum likelihood (ML) method. More complexities are seen in case of symbol recovery, synchronization [2], channel estimation [3], and MIMO preprocessing [4]. These issues necessitate the formulation of approaches which enhances reliability,
reduces cost, development time and enables extensive experimentation before finalizing a product layout. In this respect, a frequently adopted option is design of test beds to validate algorithms and design aspects. Some of the currently available test beds have evolved into reliable platforms of design formulation and validation. Here, we provide certain insights into the design of test beds related to high data rate wireless systems with focus on MIMO based systems. We review some of the relevant details of a few known designs and outline certain issues and challenges related to design of test beds that serve as proof of concept platforms for emerging technologies.

2. BACKGROUND AND RELATED ISSUES

A product development cycle involving MIMO and/or MIMO-OFDM involves the use of demonstration, design and use of test beds and formulation of prototypes. During demonstration phase, the attributes and specification of a system is fixed. It involves the requirements of the end-user. The test bed is a rudimentary system that enables the testing and validation of the theoretical aspects and algorithms related to a design. It has all the essential constituents of the targeted system with the flexibility to make modifications and variations. The test bed enables testing of the concepts in real-time and collection of the data for analysis. It is connected to a host system normally a computer which runs the drivers and protocols to facilitate a smooth transfer of data both ways. The outcome of the experimental phase involving the test bed enables the fixation of the components, provisions and attributes of a prototype. Design attributes of test beds are fixed depending upon the objective of the design. Depending upon the requirements, MIMO test beds can be categorized as software-defined, high performance real-time and field programmable grid array (FPGA) or digital signal processor (DSP) based [5]. In the first type, the system is connected to a host computer. Data are send to the test bed, processed and send back for analysis. The processing takes place off-line. Though it is a rather slow process, its simplicity helps to ascertain the performance of the formulated algorithms. Sometimes the test beds have a common clock for simultaneous processing and synchronization. It is a fast approach and the processing and data analysis involves the test bed systems. At times the hardware requirements are fulfilled using FPGA and DSP processors. It enables the testing of visualized system attributes and formulated algorithms. Test beds maybe formulated using connectors, digital-to-analog conversion (DAC) and analog-to-digital conversion (ADC) modules, and super-heterodyne radio frequency (RF) chains, encoder/decoder blocks, power amplifiers, couplers etc. These are configured to work together to enable processing of data as per requirements. Figure 1 shows the layout of a generic MIMO test bed. It is connected to a host computer. It may have multiple connector options. The interface
layer facilitates translation of codes from a high level programming environment like Matlab to DSP or FPGA specific code and vice versa. Analysis maybe performed in the computer. The data processing, modulation, baseband processing including OFDM generation and coding maybe performed using either DSP or FPGA based algorithms. The system may have dedicated real time processing provision.

3. MIMO TEST BED DESIGNS-
REVIEW OF SOME REPORTED SYSTEMS

Some of the reported MIMO test bed designs have enabled the validation of symbol recovery and detection, synchronization, channel estimation, pre-processing, encoding/decoding etc issues in real time as precursors to actual design. The working methodology of the reported test bed designs can be categorized into offline and online modes depending upon which related interfaces and drivers are formed. The design trends of test beds show that the initial attempts have been around the use of digital capture cards connected with a computer to process data offline. Next, the efforts have been towards accelerating the processing cycles for which DSP processors have been preferred. Clocking issues of DSP processors necessitated the use of application specific integrated circuits (ASIC) complicating designs and subsequently FPGAs started to get acceptance as more reliable options. Here, we describe a few test beds focusing upon key attributes and capabilities.

The vertical Bell Laboratories Layered Space-Time (V-BLAST) represents a successful attempt to obtain high data rates and spectral efficiencies of 20-40 bps/Hz in rich scattering wireless environments. The V-BLAST architecture has been implemented in laboratory condition [6]. The Hydra [7] is an offline test bed that enables laboratory experiments using low cost Ettus kits. Real time processing for multi antenna systems have been demonstrated and reported in [8]. The design formulates mechanisms of MIMO signal processing using FPGAs and DSPs. The system demonstrates spectral efficiencies of 20 bits/s/Hz and higher and a throughput of more than 150 Mbps with single-carrier transmission. The SABA is a real time MIMO system [9] test environment for high data rate transmissions in frequency-selective environments. The system uses a highly parallel processor to perform the algorithms in real time, as well as the analog front-ends. Authors of [10] report the design of a four Tx-Rx experimental set-up to validate the effectiveness of the MIMO-OFDM combination. The design in a typical indoor environment, achieves a peak data rate of 525 Mbits/s and a spectral efficiency of 19.2 bits/Hz/s. Vienna test bed [11] is a flexible instrument developed to examine MIMO algorithms and channel models at 2.45 GHz through real, physical channels, supporting simultaneously four Tx-RX antennas. A portable 4 × 4 MIMO test bed designed using FPGAs and operating in 902–928MHz ISM band has been reported in [12]. The system enables a ray-tracing analysis performed and the simulated channel capacity has been found to be closely matching to expected results. In order to experimentally establish the validity of modeling assumptions and translate these to designs suitable for the real world, a prototype is reported in [13]. The work shows the mapping of the algorithmic functionality onto the target prototyping platform. The space-time array research (STAR) platform [14] is an FPGA based design. It supports twelve 20 MHz bandwidth channels of real-time, space-time, and MIMO processing. The frequency is around 2.4 GHz. The FPGA-based solution is reported as an aid to traditional DSP based designs. It achieves a peak bidirectional data throughput of 10.8 Gbps for 12-channel I/Q after decimation-by-two. The effectiveness of FPGA based test beds have been highlighted in [15]. Algorithms and architecture for an efficient circulant approximation-based MIMO equalizer architecture for the CDMA downlink is highlighted in [16]. Certain implementation issues of MIMO systems based on simple radio hardware platform and advanced real-time signal processing and coding have been reported in [17]. A statistical analysis to assess the impact of antenna mismatches on the performance of transmit-maximal ratio combining (MRC) and the feasibility of application of scheme in a real-time wireless MIMO-OFDM test bed is described in [18]. The Virginia Tech Space-Time Advanced Radio (VT-STAR) is a DSP processor based
design [19]. The work discusses different blocks constituting the framework including the software aspects, I/O schemes with custom hardware, and data transfer mechanisms between the DSP and the host computer. In [20], Flyable OFDM MIMO (FOM) test bed is reported which is built with off-the-shelf components and can be configured with any Tx-Rx configuration with a maximum of eight pairs. It is dual-band with two carrier frequencies at 2.44 GHz and 5.245 GHz and a bandwidth of 25 MHz. In [21], a modular, reconfigurable and scalable MIMO testbed is reported which is useful for realistic scenarios at 2.45 GHz with a maximum bandwidth of 16 MHz. A 2 x 2 testbed for MIMO-OFDM IEEE 802.16 prototype has been presented in [22]. Here, channel measurements are performed at 3.5 GHz focusing on outdoor-indoor scenarios. FPGA based approach has been implemented for performing advanced signal processing to support joint channel and frequency offset estimation.

Of late the shift has been towards the design of multi user MIMO (MU-MIMO). MU-MIMO enhances system capacity by using virtual channels between a base station and multiple terminal stations. A 16 x 16 MU-MIMO test bed in an actual indoor environment achieves the frequency utilization of 870 Mbps and 1 Gbps (SNR: 31 and 36 dB) with 20 MHz bandwidth, respectively [23]. Another work [24] uses a FPGA based approach to design and MU- MIMO using OFDM. A VLSI based approach is reported in [25] which for an 8 x 8 MIMO achieves near maximum likelihood bit error rate at 57.6 Mbps. In [26], a real time test bed for Worldwide Interoperability for Microwave Access (WiMax) experiments based in MIMO technology has been reported. The rate selection and adaptation is a critical issue in real time MU-MIMO. Certain issues in this regard have been addressed in [27]. The first open MU-MIMO Software-Defined Radio (SDR) platform using frequency range, from 300 MHz to 5.8 GHz has been reported in [28]. The work reports over-the-air experiments to evaluate the potential of UHF-band MU-MIMO.

The recent developments indicate a trend towards design of scalable and reconfigurable test beds so as to extend the capacity limits of MIMO systems.

4. CONCLUSION

In this paper, we have provided an overview of MIMO test bed as an instrument of performing experiments in real time to validate theoretical concepts. We first discussed about the importance of test beds, their types and the generic constituents. Next, we discussed a few works which highlight the different stages of MIMO test bed development. Starting with the basic offline systems, we discussed certain frameworks based on DSP and FPGA approaches. Many of the discussed works focussed on achieving higher spectral efficiency and capacity. Certain works focussed in signal processing and coding aspects. The trend has been towards design of modular, scalable and reconfigurable test beds. Many works are integrating WiMax systems and WLAN attributes to enhance the versatility of the systems. Lately, researchers have started to focus on MU-MIMO based designs as it is likely to be the cornerstone of upcoming wireless technology.

REFERENCES


