Towards Integrating Pattern Reconfigurable Antennas in WiMAX/LTE Radios

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***Abstract*—The integration and deployment of pattern reconfigurable antenna arrays in real-world wireless systems have been inhibited by the prohibitively high costs of implementation and integration infrastructure. As a result, many research institutions have turned to Software-Defined Radio (SDR) solutions as a cost-efficient alternative. This work discusses various relevant platforms that could be used for integrating pattern reconfigurable antennas in 4G radios. We also leverage an open, programmable testbed to evaluate the performance of a pattern reconfigurable antenna array as part of the holistic wireless system.**

***Index Terms*—Pattern Reconfigurable Antennas, WiMAX/LTE, Software-Defined Radios**

I. Introduction

Tremendous progress has been made in the research of adaptive antenna systems such as reconfigurable antennas; numerous designs are agile and reconfigurable in frequency, pattern, polarization, or a combination of these parameters. However, although several of these antenna designs and prototypes have been analyzed and tested in the laboratory setting [1]–[4], the transition from laboratory testing to deployment is still a challenge. The integration and deployment of this antenna prototypes in real-world wireless systems have been inhibited by the prohibitively high costs of implementation and integration infrastructure. As a result, many research institutions have turned to Software-Defined Radio (SDR) solutions to implement radio communications systems [5]–[9]. In this work, we discuss various examples of relevant cost-efficient platforms for integrating these antenna systems and propose an experimental platform for performance evaluation of the integrated system.

Technically, SDR solutions enable the replacement of hardware specific components with their software implementation. SDR defines a collection of hardware and software technologies where some or all of the radio's operating functions (also referred to as physical layer processing) are implemented through modifiable software or firmware operating on programmable processing technologies. These devices include field programmable gate arrays (FPGA), digital signal processors (DSP), general purpose processors (GPP), programmable System on Chip (SoC) or other application specific programmable processors. The use of these technologies allows new wireless features and capabilities to be added to existing radio systems without requiring new hardware [10]. This flexibility have therefore enabled the use of commercial off-the-shelf (COTS) technologies as a cost-efficient alternative infrastructure for testing SDR based communication systems.

Several research works [11]–[15] have leveraged COTS to build state-of-the-art wireless communication testbeds for testing the performance of various wireless radios and algorithms. These testbed prototypes are generally built around high-performance hardware such as FPGAs and DSPs, the Universal Software Radio Peripherals (USRP) and readily-available wireless base stations. The works in [11] –[13] implement PHY layer protocols in SDR but decouples protocols associated with other OSI layers of the communications system such as the data link/MAC, network/IP, or transport layers. Their studies deal exclusively with PHY layer analysis without a holistic implementation of the communication system. The testbed in [14], however, uses a suite of open-source SDR frameworks to develop and implement all the OSI layers in a MIMO testbed known as Hydra. This testbed also leverages the readily available USRP hardware – designed primarily for accessibility and based on open source software suites – for testing the performance of a MIMO wireless protocols.

The work in [15] leverages the capability of a WiMAX femto base station, an Access Service Network (ASN) gateway, and Linux servers that are readily available to develop a WiMAX network testbed. The base station is a programmable PicoChip WiMAX platform based on the IEEE 802.16e standard [16]. The testbed was specifically used for testing multicast video delivery schemes for 4G wireless networks. However, SDR platform solutions similar to that in [15] tend to be more costly than anticipated and may not be affordable by many research laboratories. Fortunately, as part of a collaborative project known as GENI – Global Environment for Network Innovations– WiMAX project [17]– our institution has access to a state-of-the-art Air4G WiMAX base station. Our work, therefore leverages this open, programmable and virtualizable node, as one of the key enabling technologies for testing pattern reconfigurable antenna arrays.

In Section II, we present the proposed 4G testbed and briefly discuss the hardware technologies used. In Section III, we describe the experimental setup and evaluation methodology, and then, analyze the experimental performance results in Section IV. Section V gives a brief conclusion.

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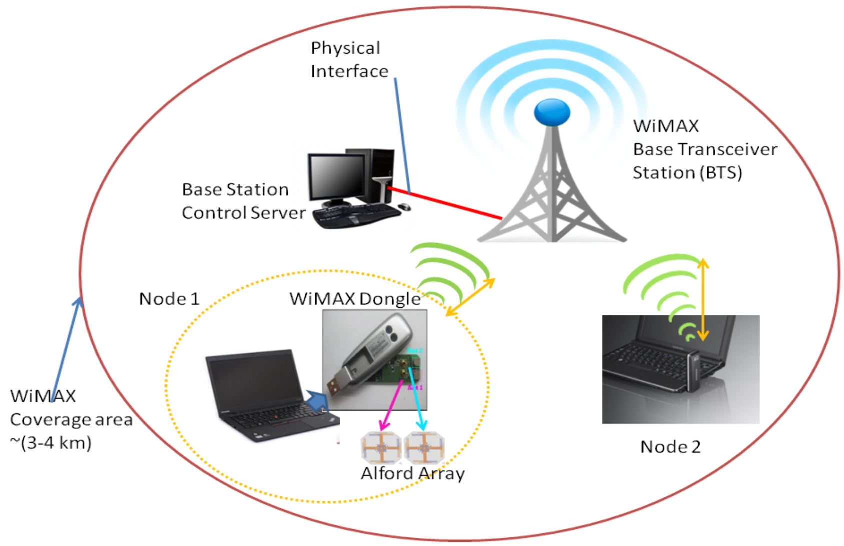

Fig. 1. A High level Schematic of the Proposed Testbed

II. WiMAX/LTE Testbed

Our proposed testbed comprises of an Air4G WiMAX base station – a multi-platform technology that integrates both WiMAX and LTE-Advanced, a control server, and multiple wireless clients.

A. WiMAX Base Station Hardware

The base station is equiped with Quad port and 90 degree sector antennas. It operates in the 700 MHz, 1.4 GHz, 2.3 – 2.7 GHz and 3.3 – 3.8 GHz bands. It has four receivers and four transmitters. It supports both TDD and FDD standards for multiplexing; in the TDD mode the subchannels for the Downlink (DL) and Uplink (UL) can be partitioned into multiple time-frequency configurations. In the mobile WiMAX mode, Air4G supports 3.5, 7, and 10 MHz bandwidth channel sizes. However, it is capable of supporting upto 20 MHz PHY/MAC channels when in the LTE mode. It can run both WiMAX and LTE modes concurrently and support standard adaptive modulation schemes based on QPSK, 16QAM, and 64QAM.

B. Reconfigurable Antenna Hardware

The antenna design first presented in [18] is a reconfigurable Alford Loop that operate in the frequency band between 2.5 – 2.7 GHz. It was designed to generate omnidirectional and directional beams in a single planar design. This antenna consists of microstrip elements activated using PIN diode switches. When employed in a 2-element array, the different pattern configurations result in different mutual coupling and envelope correlations; these pattern configurations were characterized in [19].

C. Testbed Setup

Fig. 1 depicts the testbed setup. The base station is configured to operate in the licensed center carrier frequency of 2.59 GHz with a 10 MHz bandwidth. The control server runs Windows Server 2008 operating system with a 2.33 GHz processor and 2 GB of RAM memory. The clients run on Windows operating systems and one of the clients, Node 1, is connected to a 4G WiMAX dongle via a USB interface. The dongle has two external antenna ports that enables the connection of the reconfigurable Alford antenna array to it; the array is in turn connected to a control board for switching between different modes. The other client, Node 2, is also equipped with a Tecom 2.5 GHz WiMAX USB dongle as illustrated. The WiMAX clients are associated with the WiMAX base station through the control server which acts as the Access Service Network gateway. The controller also hosts a DHCP server and dynamically assigns IP addresses to new clients from a pool of available addresses. Additionally, it controls and maintains both downlink and uplink connections between the base station and the clients through service flow configuration.

III. Experimental Evaluation

A. Parameters: WiMAX PHY/MAC Profiles

The BS PHY profile is set to the TDD mode and the OFDMA channel properties are set as follows: Downlink to Uplink ratio of 29:18, bandwidth of 10 MHz, OFDMA FFT size is set to 1024 and the frame period to 5 ms, and HARQ is set to enabled. The downlink channel is set to operate at carrier frequency of 2.59 GHz, EIRP of 30 dBm and transmit power of 30 dBm. For the purpose of mimicking a 2x2 MIMO system, the BS RF profile is set to use 2 antennas. The downlink sub-frame mode property is set to full channel and the MIMO matrix is set to dynamic when testing in the performance of the system the in multimode MIMO state; where it switches between three modes: beamforming, spatial diversity, and spatial multiplexing. The MIMO matrix is set to MIMO matrix B for the state where spatial multiplexing technique is required. The uplink subframe mode property

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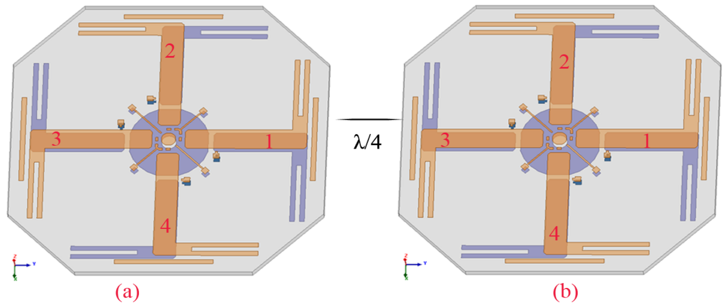

Fig. 2. Reconfigurable Alford Loop Array

TABLE I
SYSTEM PARAMETERS

Parameters	Value
Frequency	2.59 GHz
Duplex	TDD
Bandwidth	10 MHz
BS Antenna Gain	17 dBi
MS Antenna Gain	1.8 dBi
BS Max Power	43 dBm
BS Noise Figure	4 dB

TABLE II
OFDMA PARAMETERS

Parameters	Value
Channel Bandwidth	10 MHz
Sampling Frequency	11.2 MHz
FFT Size	1024
Subcarrier Spacing	10.94 kHz
Symbol Time	91.4 μs
Cyclic Prefix	11.4 μs
Symbol Duration	102.9 μs
Frame Duration	5 ms
OFDMA Symbols	48

is also set to full channel and the maximum HARQ ACK subchannels is set to 15. Both uplink and downlink burst profiles are set to adaptive modulation and coding based on the modes defined in [16]. This modulation or constellation range from {QPSK , 16QAM, 64QAM }, while the FEC coding rates are {1/2, 2/3, 3/4, 5/6}. Both convolutional code and convolutional turbo code with variable code rate and repetition coding are supported; in this experiments we used convolutional turbo code. Tables I and II summarizes the main system and OFDMA parameters used.

B. Measurement Methodology

Throughput measurements are commonly performed by sending a large file from one peer to another. In this methodology, the file size is divided over the transfer time duration and the achieved throughput in bits per seconds is measured. However, this method measures application throughput of the established link, which essentially describes the throughput without protocol overheads from other layers such as the transport or network layers. However, as demonstrated in [20] the upper bounds for the expected throughput rates measured at the application layer yields the same performance as measurements based on PHYsical or transport layer methodology. The works in [20] and [21] provides benchmarks for throughput measurements obtained at various OSI-model layers. Fig. 3 illustrates the overall network architecture and the main components of the setup based on the OSI-model layers.

In this experimental setup we used the IPERF application for streaming traffic UDP/TCP traffic to measure maximum DL/UL throughput. In order to test the different PHYlayer algorithms, we leveraged the programmability of the base station to configure the settings as described the above. First, we test the multimode PHY layer algorithm that enables the system to dynamically switch between three multi-antenna architectures: beamforming, Spatial multiplexing and spatial diversity. For operation in the multimode state, we configure the base station downlink subframe property, MIMO matrix, to "dynamic". Similarly, to benchmark performance in this state against the proposed algorithm that uses spatial multiplexing, we also make measurements when the BS downlink property, MIMO Matrix is set to "Matrix B".

We note, that the same antenna array is used in the two measurement scenarios: in the multimode scenario, all the antenna elements of the array are set to operate in the omnidirectional state; while in the reconfigurable scenario, antenna mode switching is allowed. In order to avoid synchronization issues in the switching of the antenna states, we take measurements using each of the antenna array states in a round-robin fashion and process the results offline. Thus, one packet per antenna state is transmitted during each transmission period. We assume that the channel environment is semi-static during the period of transmission that spans all the antenna states. Also, since the reconfigurable Alford is a directional microstrip antenna and the client node is fixed, the number of antenna array states can be minimized.

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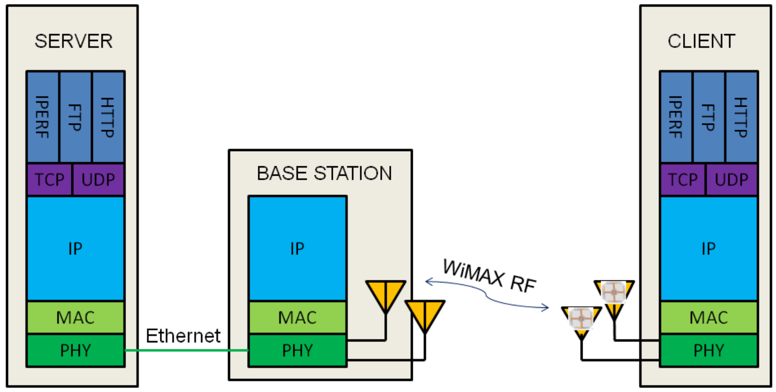

Fig. 3. WiMAX Setup Architecture

IV. Performance Evaluation

In this section, we present the throughput and PER measurement results and provide explanations for the observed performances. We benchmark the throughput performance against the value of achievable throughput on the derivations in [22]. The achievable throughput is derived from the mutual information or capacity of the channel and accounts for inherent system losses and is given by (1) [22]:

$$D_{achievable} = \frac{1}{1+GI}\frac{1/T_s}{N_{FFT}}\frac{N_{data}}{N_{OFDM}} * C_{Shannon} \quad (1)$$

where GI corresponds to the ratio of cyclic prefix time and the useful OFDM symbol time, N_{FFT} is the OFDM size, N_{data} is the number of OFDM data symbols, N_{OFDM} is the total number of OFDM symbols in one transmission frame, and T_s is the sampling rate of the transmit signal. $C_{Shannon}$ is the theoretical Shannon capacity given by $log_2(1+SNR)$.

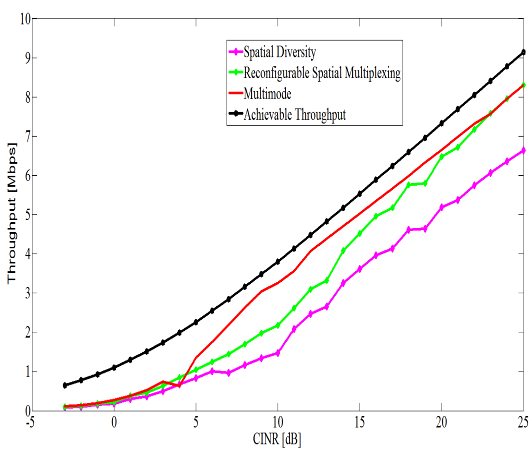

Fig. 4. Downlink Throughput Performance against CINR

Fig. 4 depicts the achieved throughput and the measured throughput for the two measurement scenarios. It can be observed that the throughput achieved from the multimode state outperforms the throughput in the reconfigurable state. This can be attributed to the usage of higher modulation orders

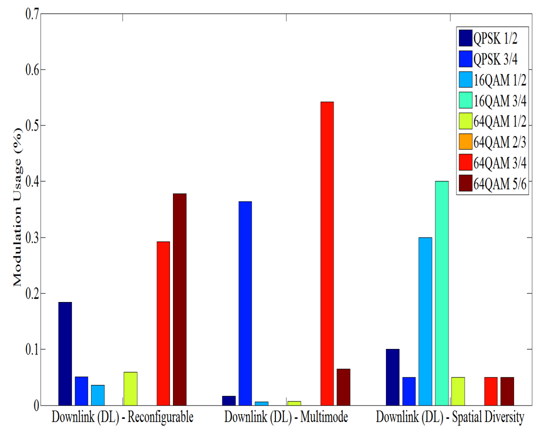

Fig. 5. Downlink Modulation Usage Performance

in the multimode state as can be observed in Fig. 5. The lack of seamless antenna state switching in the client receiving array and other imperfections or constraints of the proposed system might also affect the overall throughput performance.

V. Conclusion

In this work, we presented an overview of software defined radio platforms and the relevant technologies that are often used for testing multi-antenna systems. We then focused on developing a platform for integrating pattern reconfigurable antennas in a 4G systems. Specifically, we discussed an experimental testbed that leverages an open, programmable base station to evaluate the performance of reconfigurable antennas. We developed a performance testing methodology and presented the results from an experimental test campaign. These results effectively demonstrate the functionality of the pattern reconfigurable antennas as part of the holistic 4G system. Future work, will focus on improving the efficiency of antenna state switching in a multi-antenna system that uses these pattern reconfigurable antennas.

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