Designing a 5G System for Localization and Communication

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***Abstract*—The main goal of this project is to investigate the implementation of a 5G communication system for the Internet of Things (IoT) lab on campus. Operating in the 5G band would open the class up for new projects that utilize communication at much higher frequency bands beyond the Wi-Fi data high-traffic at 2.4GHz and 5GHz. The first stage of this project is to establish a 16 GHz communication link using commercial off-the-shelf (COTS) components. Analog Devices' ADAR1000 beamforming chip will function as the heart of the beamsteering network, operating as both a transmitter and a receiver. Constructing the system will begin with manufacturing printed circuit boards (PCBs) that can properly house the ADAR1000 chip. Once a reliable, line-of-sight communication link has been established, the next step of the project will be to steer the beam to specific points in the room. After the beamsteering capabilities of the system have been established, an upconverter and high-frequency Field Programmable Gate Array (FPGA) will be added to the input of the beamforming network, facilitating the transmission of coherent, modulated data on the beam.**

***Index Terms*— Commercial Off-the-Shelf (COTS), Millimeter-Wavelength (MMW), Beamforming**

I. Introduction

THERE are numerous examples in scientific literature that document the fabrication of 5G communication systems, or propose innovative methods to integrate into existing systems. One example is a study that modified the firmware on the TP-Link AD7200, a commercial-off-the-shelf (COTS) 60 GHz router, to allow for user control over the beam patterns of the antenna array [1]. Another group used other commercial millimeter wave (MMW) hardware to test various localization algorithms at 60 GHz [2].

Naturally, there has been interest in developing a 5G communication system in the Internet of Things (IoT) lab on campus. This would open the class up for new projects that utilize communication at much higher frequency bands. Furthermore, future students would be able to pursue their own research efforts in the 5G band, knowing that they have a physical system to validate their ideas in the networking and communications area.

II. System Design

A number of COTS products were researched for the central beamforming component of the system. A significant amount of the initial research was focused on the aforementioned TP-Link AD7200, primarily for its 60 GHz beamforming hardware. This hardware is not easily accessible, however; full control over the hardware can only be acquired by jailbreaking the commercial firmware on the device. On the contrary, the Taoglas KSF410.A is designed for full user control, and operates at 28 GHz [3]. Although they were both promising options, both the Taoglas and TP-Link products were not commercially available, and were not selected.

The Analog Devices ADAR1000 beamforming chip was selected as the central component of the system, which can be seen in Figure 1. The core capabilities of this device allow for a great degree of design flexibility for a prospective researcher, and the power specifications are more than adequate for a lab environment. A Raspberry Pi outputs the necessary beamforming parameters to an SPI bus, which allows for full phase control of the four TX/RX channels. The four channels are passively combined to steer the beam towards a given direction. The maximum frequency of the device is 16 GHz, which is a good compromise in terms of frequency location and simplification of the interface with the end user [4].

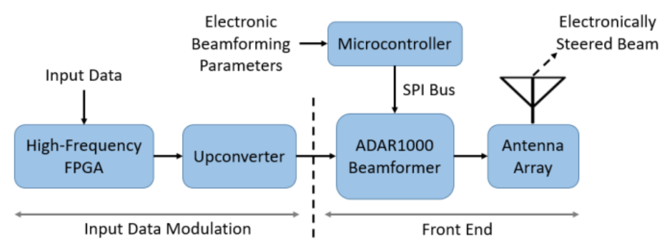

Fig. 1: System Diagram outlining connections between stages.

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Professor Mona Hella is a professor at Rensselaer Polytechnic Institute (e-mail: hellam@ecse.rpi.edu).

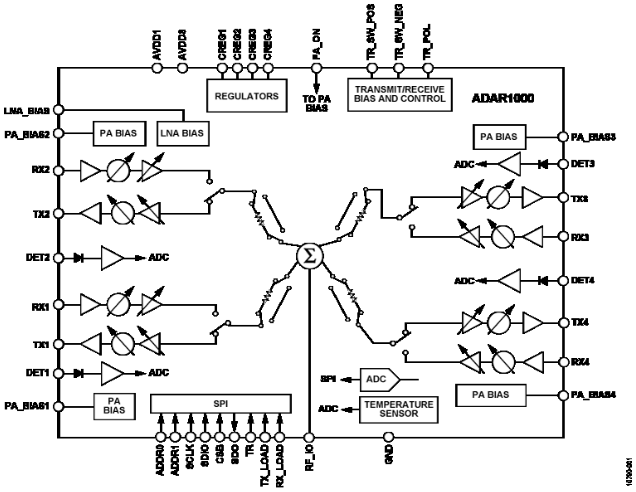

Fig. 2: Functional Diagram of ADAR1000 Beamformer

The theoretical maximum range between two transceivers, *d*, with one setup as a transmitter and one as a receiver, can be calculated through the path loss equation [5]. Inputting the maximum output power of the chip in transmit mode, $P_{TX} = 13$ dBm, the minimum input power for detection in the receive mode, $P_{RX} = -20$ dBm, the gain of a microstrip double arrays antenna [6], $G_{TX} = G_{RX} \sim 10$ dB, and the frequency, $f = 16$ GHz, yields a range of 0.66 m. The range can be increased in the future through additional amplifiers and improved antennae.

$$P_{TX} - P_{RX} = 20\log(d) + 20\log(f) + 20\log\left(\frac{4\pi}{c}\right) - G_{TX} - G_{RX} \quad (1)$$

All the components that have been discussed comprise the Front End of the system; the Front End takes any in-band signal as input and transmits it to a chosen direction. The Input Data Modulation portion of the system is comprised of the Upconverter and High-Frequency FPGA. Arbitrary data can be transmitted over the steered 16 GHz beam after being modulated by the FPGA and upconverted to the 8-16 GHz band.

III. Evaluation Plan

Evaluation of the system will be done in incremental steps, with more complexity being added as each sub-system is demonstrated. To start, a high frequency signal generator outputting an unmodulated sinusoidal wave will feed into the input of the Front End stage. Once reliable line-of-sight communication is established at 0.5 m of range, the specifications of the steered beam will be measured; these include the maximum range, R_{max}, the beamwidth, w, the resolution of the beam direction, $\Delta\theta$, and the maximum update rate for any change in beam direction, which is $\Delta\theta$ divided by the update time.

The specifications outlined above will be repeated with the Input Data Modulation stage added to the input of the Front End. The system has not been physically realized or tested, but a well-defined direction and foundation for the project has been established for the future owners of the project. At this phase, a number of printed circuit boards (PCBs) have been fabricated that will house the bare dies from Analog Devices. The boards have been received and the dies will be wirebonded to the PCBs once the labs on campus are open for testing.

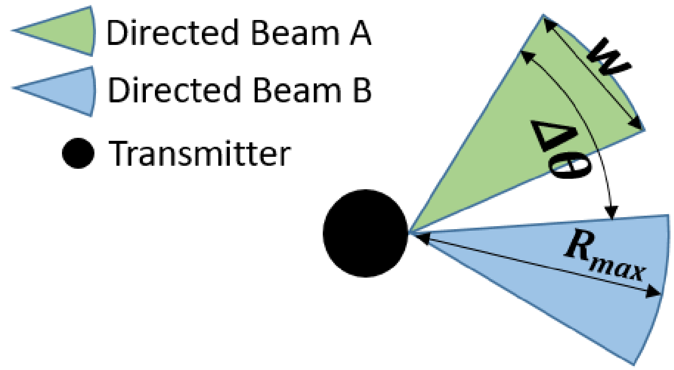

Fig. 3: Bird's Eye (Top) View of the Transmitter, visualizing the parameters being measured.

IV. Acknowledgements

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