Demo: ArgosV3: An Efficient Many-Antenna Platform

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ABSTRACT

We present the third generation of Argos platforms, ArgosV3, intended for real-world applications and research. Developed from scratch specifically for many-antenna MU-MIMO, ArgosV3 is highly efficient in space, power, computation, and cost. While this new platform is highly configurable, featuring FPGA SoCs and frequency agile transceivers capable of operation from 50 MHz to 3.8 GHz, it is also highly compact and power efficient, enabling a complete 160 radio base station in less than 2 ft^3. ArgosV3 is currently being deployed in a campus-wide multi-cell many-antenna network. For our demonstration we will show a single ArgosV3 base station serving multiple clients using a realtime LTE stack.

1 INTRODUCTION

Many-antenna MU-MIMO, or Massive MIMO at large scales, can improve spectral efficiency by and order of magnitude, and is a key candidate technology for next-generation wireless systems. Over the past few years multiple experimental testbeds have been released [1–3, 5, 9, 10]. These testbeds have been instrumental in testing, validating, and improving many-antenna MU-MIMO technologies, however as initial prototypes and research equipment they are cumbersome, expensive, and limited to laboratory-scale experiments.

Leveraging our experience in building ArgosV1 and ArgosV2 [9, 10], we designed and built ArgosV3 from scratch to support real-world many-antenna MU-MIMO. ArgosV3 is very configurable and scalable, while being highly efficient in space, power, computation, and cost. The ArgosV3 base station is composed of three components: 1) a central controller, 2) a hub, and 3) multiple radio modules, which are capable of being daisy-chained. Notably, ArgosV3 fully implements the original Argos architecture [9], and as such is extremely scalable: from just a few base station antennas to hundreds, or even thousands. A single ArgosV3 hub currently supports over 300 radios, and multiple hubs can be used in a single base station. To enable mobile experiments, we also designed a compact battery-powered ArgosMobile, based on the same radio module as the base station.

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ArgosV3 supports multiple design flows, however for this demonstration we leverage the OpenAirInterface realtime LTE stack [6] to show an ArgosV3 base station serving multiple MU-MIMO clients simultaneously.

2 DESIGN

Based on our experience building two previous generations of many-antenna base stations, we designed ArgosV3 to be incredibly scalable, flexible, and usable. ArgosV3 fully supports the Argos architecture [9], and is provisioned to support streaming massive MIMO applications with up to 56 MHz of bandwidth. By employing frequency-agile transceivers and modular frontends, ArgosV3 enables high RF performance from 50 MHz to 3.8 GHz. Each component in ArgosV3 runs a full Linux OS, and the system supports multiple mature software-defined radio projects, including Pothos/SoapySDR, OpenAirInterface, the Argos channel measurement system, and GNU Radio [6–8, 11]. To support truly mobile experiments, ArgosV3 also provides updated battery-powered ArgosMobiles that feature integrated GPS.

2.1 Computational Design

The ArgosV3 base station is composed of three computational components: 1) a central controller, 2) a hub, and 3) multiple radio modules, shown in Figure 1.

The central controller is a standard server, or server cluster, that can be provisioned according to the application. For some design flows the central controller provides all of the processing in the system, and simply transmits IQ values to the radio modules. If required, the central controller can leverage optional PCIe FPGA co-processors, e.g., the Xilinx ZC706 or NetFPGA [12]. The central controller is connected to one or more hubs, each with up to four 10 GbE connections, for up to 40 Gbps of connectivity per hub.

The ArgosV3 hub is based on a Xilinx ZCU102 development board with a custom daughtercard to connect to the radio modules. This daughtercard provides high-precision clocking, power, GPIOs, and up to 13.2 Gbps of bi-directional connectivity to each chain of radio modules for coherent MIMO operation. The daughtercard is provisioned to support up to 8 chains of radio modules, and contains integrated GPS to enable global time-frequency synchronization. Additionally, the Xilinx ZCU102 supports Synchronous Ethernet (SyncE) and Precision Time Protocol (PTP) for network time-frequency synchronization.

The most complex and innovative component in ArgosV3 is the radio module, called an Iris, which provides 2 independent radios. Each Iris contains a Xilinx Zynq 7030 SoC, which provides significant computational capacity with two ARM cores and FPGA

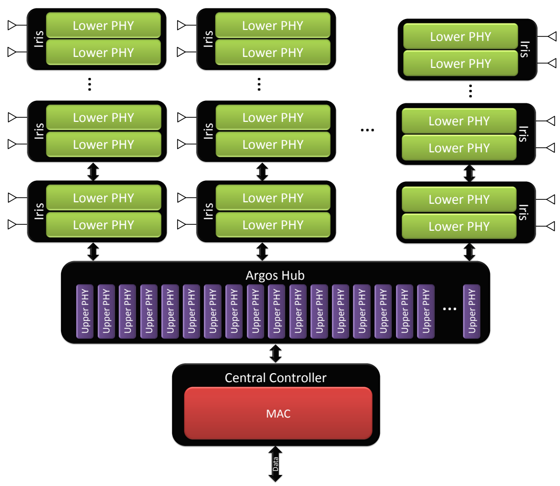

Figure 1: To enable extreme scalability, ArgosV3 can distribute computation across the central controller, hub, and radio modules.

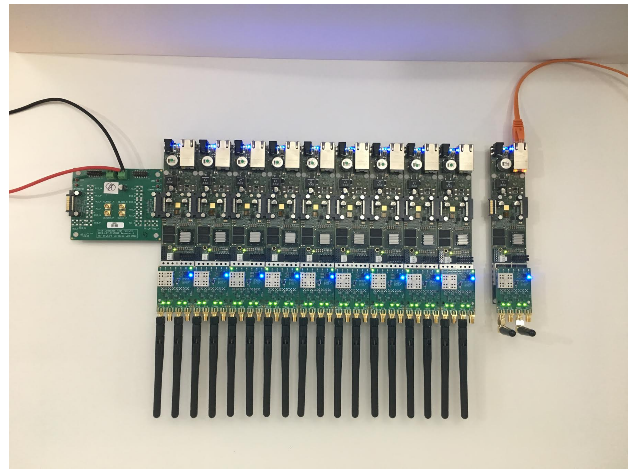

Figure 2: ArgosV3 Iris radio modules. *(Left)* A coherent 18-radio array connected through a bus providing 13.2 Gbps connectivity, shared clocks, GPIOs, and power. *(Right)* A single ArgosV3 radio module with two antennas powered with PoE.

fabric. To fully support the Argos architecture [9], Irises can be daisy chained, either with a cable, or directly attached, as shown in Figure 2. This series connected bus provides clocking, power, GPIOs, and up to 13.2 Gbps of serial connectivity, completely eliminating the need for additional cabling. While the length of chains is only limited by power, which can be injected at multiple points, for streaming designs we typically limit the chain length to 10 to manage end-to-end latency. Conveniently, Irises can also be directly powered by barrel connectors, or via Power over Ethernet (PoE). Notably, individual Irises can also be used as standalone 2 antenna clients.

2.2 RF Design

The Iris radio modules in ArgosV3 employ a modular RF design. Each Iris contains a Lime Microsystems LMS7002M frequency-agile transceiver that supports two radio chains from 50 MHz to 3.8 GHz with up to 56 MHz channel bandwidth. However, to support high performance at a given frequency, e.g., in outdoor long-range environments, band-specific components such as filters, Low-Noise Amplifiers (LNAs), and Power Amplifiers (PAs), and antennas are required. Thus each Iris connects to an interchangeable RF frontend, designed to support the targeted bands. To date, we have designed two band-specific RF frontends for ArgosV3, the first supports 470-700 MHz UHF operation with 30 dBm transmit power, and the second supports 2.4-2.7 GHz and 3.5-3.8 GHz operation with 28 dBm transmit power. For development and testing on the full 50 MHz to 3.8 GHz frequency range, we also built an RF frontend that simply passes through the RF signals to the Lime transceiver, without filtering or amplification.

Additionally, to achieve a compact form-factor, as well as simplify design and cabling, we designed dual-polarized antennas for the UHF, 2.4-2.7 GHz, and 3.5-3.8 GHz bands, each with over 5 dBi gain across their target frequencies.

2.3 Mechanical Design

ArgosV3 was designed to be versatile and highly compact, as well as support outdoor deployments. Each Iris radio module is 1.55" wide, and thus can be spaced 1/2 wavelength apart at the highest supported frequency, 3.8 GHz, when daisy-chained. Since every Iris provides two radios, dual polarized antennas can be directly attached while maintaining this compact 1/2 wavelength spacing, as shown in Figure 4. For longer wavelengths Irises can be separated by cables or spacer boards, or RF cables can be used to attach the antennas.

While each Iris was designed to be very power efficient, consuming less than 15 W depending on design and transmit power, in dense configurations heat dissipation is a concern. Thermal considerations are even more challenging for outdoor deployments, where the base station needs to be weatherproofed. To address this issue we built a compact enclosure which provides two fully enclosed extruded heatsinks that span every chain of Irises, one for the Zynq processing unit, and one for the RF power amplifier. These heatsinks have fans at both ends to provide forced-air cooling. This weatherproof compact enclosure, containing a hub, 80 Irises, and antennas, is only 18"x14.5"x13", providing 160 radios in just 2 ft^3. A UHF version that is approximately 40"x20"x6", shown in Figure 3, is currently being finalized. This UHF enclosure contains 16 radios, and while it can be used standalone for small-scale deployments, to support massive MIMO multiple enclosures are deployed and connected to an ArgosHub.

2.4 Software Frameworks

ArgosV3 contains both CPUs and FPGA resources in all of its components, enabling it to support virtually any software framework. While not required, for convenience we typically run a full Linux OS on each radio module, as well as the hub and central controller. ArgosV3 supports multiple mature software-defined radio projects, including Pothos/SoapySDR, OpenAirInterface, the Argos channel measurement system, and GNU Radio [6–8, 11].

Pothos and GNU Radio provide similar features for rapid prototyping of research systems, including high-level language support, e.g., Python, a plethora of sample code, and even GUI interfaces. The Argos channel measurement system provides a framework for flexibly capturing and analyzing high time-frequency resolution

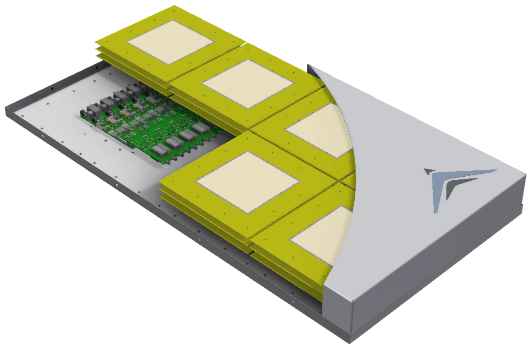

Figure 3: Rendering of UHF enclosure with 16 radios connected to 8 dual-polarized antenna elements. This enclosure is approximately 40"x20"x6" and is currently being finalized for production. To scale to massive MIMO, multiple UHF enclosures are deployed and connected to an ArgosHub.

Figure 4: Complete ArgosV3 base station with 160 radios designed for 3.55 to 3.75 GHz operation. This compact cube is only 18"x14.5"x13". The plastic radome is removed to show the 80 dual-polarized antenna elements in a 10x8 configuration.

channel traces for many-antenna MU-MIMO. Finally, OpenAirInterface provides a production quality realtime LTE implementation entirely in software (C).

2.5 ArgosMobile

Since the capacity of MU-MIMO is fundamentally limited by mobility, ArgosV3 provides compact battery-powered clients to enable truly mobile experiments in diverse environments. This ArgosMobile is currently based on the same Iris radio module used in the base station, however it leverages a custom 3D printed enclosure that also contains 26650 Li-Ion batteries in a 3S2P configuration to provide roughly 8 hours of power in a 2"x2.5"x10" form-factor. A modified Iris that includes integrated GPS, a battery controller, and a USB WiFi bridge is currently being finalized.

3 DEMONSTRATION

In this demonstration we show an ArgosV3 base station running a realtime LTE stack serving multiple clients simultaneously. We ported the open-source OpenAirInterface LTE eNodeB and UE implementation [4, 6] to the ArgosV3 platform, and show that it is capable of serving 4 users simultaneously with up to 64 base station antennas, as supported by the LTE standard release 10.

For this demonstration we will need a medium sized table, e.g. 3'x6' and a standard power strip; internet access would be preferable, but is not required. We will provide all equipment, including a base station and multiple clients. It should take between 30 minutes and an hour for us to setup.

4 CONCLUDING REMARKS

We present ArgosV3, a novel many-antenna MU-MIMO platform designed from scratch to support real-world deployments of massive MIMO. ArgosV3 fully implements the Argos computational architecture, enabling unprecedented scalability and flexibility in a space, power, computation, and cost-efficient design.

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REFERENCES

[1] 2017. Bristol and BT collaborate on massive MIMO trials for 5G wireless. http://www.bris.ac.uk/news/2017/february/massive-mimo-trials.html. (2017).

[2] Neeraj Choubey and Ali Panah. 2016. Introducing Facebook's new terrestrial connectivity systems - Terragraph and Project ARIES. https://code.facebook.com/posts/1072680049445290. (2016).

[3] Xiang Gao, Fredrik Tufvesson, Ove Edfors, and Fredrik Rusek. 2012. Measured propagation characteristics for very-large MIMO at 2.6 GHz. In *IEEE Asilomar Conference on Signals, Systems, and Computers*. IEEE, 295–299.

[4] Xiwen Jiang and Florian Kaltenberger. 2017. Demo: an LTE compatible massive MIMO testbed based on OpenAirInterface. (2017).

[5] Nutaq. 2017. TitanMIMO. https://www.nutaq.com/5g-massive-mimo-testbed. (2017).

[6] OpenAirInterface: 5G software alliance for democratising wireless innovation. 2017. http://www.openairinterface.org/. (2017).

[7] Thomas W Rondeau. 2015. On the GNU Radio Ecosystem. *Opportunistic Spectrum Sharing and White Space Access: The Practical Reality* (2015), 25–48.

[8] Clayton Shepard, Jian Ding, Ryan E Guerra, and Lin Zhong. 2016. Understanding real many-antenna MU-MIMO channels. In *Signals, Systems and Computers, 2016 50th Asilomar Conference on*. IEEE.

[9] C. Shepard, H. Yu, N. Anand, E. Li, T. Marzetta, R. Yang, and L. Zhong. 2012. Argos: Practical Many-Antenna Base Stations. In *Proc. Ann. Int. Conf. Mobile Computing & Networking (MobiCom)*.

[10] Clayton Shepard, Hang Yu, and Lin Zhong. 2013. ArgosV2: A Flexible Many-Antenna Research Platform. In *Extended Demonstration Abstract in Proc. ACM MobiCom*.

[11] The SoapySDR Project. 2017. https://github.com/pothosware/SoapySDR/wiki. (2017).

[12] Noa Zilberman, Yury Audzevich, G Adam Covington, and Andrew W Moore. 2014. NetFPGA SUME: Toward 100 Gbps as research commodity. *IEEE Micro* 34, 5 (2014), 32–41.