ArgosV2: A Flexible Many-Antenna Research Platform

Clayton Shepard, Hang Yu, and Lin Zhong
Rice University, Houston, TX
{cws, hang.yu, lzhong}@rice.edu

ABSTRACT

Many-antenna base stations are a rapidly growing field in wireless research. A plethora of new theoretical techniques have been recently proposed for many-antenna base stations and networks. However, without experimental validation, it is difficult or impossible to predict the practicality and performance of these techniques in real hardware, under complex, rapidly varying, real-world conditions. Indeed, there is a significant demand for a flexible many-antenna research platform which supports rapid prototyping and validation of new massive-MIMO techniques.

Leveraging our experience building *Argos*, a 64-antenna base station prototype, we have designed and built *ArgosV2*, a compact, powerful, and scalable many-antenna research platform based on WARP. In addition to the physical hardware and mechanical design, we are developing a software framework, *ArgosLab*, which will provide synchronization and channel estimation, greatly reducing the development effort for a wide range of massive-MIMO techniques. ArgosV2 is intended to provide ultimate scalability and programmability for experimental massive-MIMO research. The modular architecture and real-time capability of ArgosV2 can support up to 100s of base station antennas and 10s of users with streaming applications. We present a 96-antenna base station which supports real-time streaming applications to 32 users simultaneously.

1. INTRODUCTION

Due to the popularization of mobile devices such as smartphones, tablets and data-hungry applications, mobile data traffic is growing exponentially. One approach to satiate this increasing demand for wireless capacity is large-scale MU-MIMO, which is commonly referred to as *massive-MIMO*. Massive-MIMO theory predicts that with M antennas on the base station, or in the network, up to M users can be served simultaneously, leading to a linear increase in network capacity. Not surprisingly, many wireless researchers are envisioning the next generation base stations to have hundreds, or even thousands, of antennas which realize the benefits of massive-MIMO [1]. Over the past few years, there has been a plethora of new massive-MIMO techniques proposed, such as [2, 3, 4, 5], and many more.

However, to date, most research regarding massive-MIMO has been restricted to theory that is based on analytical or simulation results. The lack of an experimental platform has prohibited the validation of theoretical results and understanding of the impact of real-world factors on the performance of massive-MIMO. Our previous work [6] demonstrated that a properly designed architecture can realistically scale up to 100s of antennas serving 10s of users simultaneously; however, our initial prototype used antiquated hardware which was bulky, and not flexible and powerful enough to enable real-time wideband MU-MIMO applications. We believe it is critical for the area of massive-MIMO to have an experimental research platform that allows rapid prototyping of new massive-MIMO techniques for real-time streaming applications. Leveraging our experience from the initial Argos prototype, we have refined the Argos design to be more powerful, compact, robust, and scalable; this substantial revision we refer to as *ArgosV2*. Unlike Argos, ArgosV2 supports rapid prototyping of real-time many-antenna applications with extreme scalability, programmability, portability, and performance. We draw the parallel from ArgosV2 to similar platforms used for rapid implementation and testing of small-scale wireless techniques, such as WARP and Sora [7, 8], which have proven to be invaluable for novel research in PHY and MAC designs.

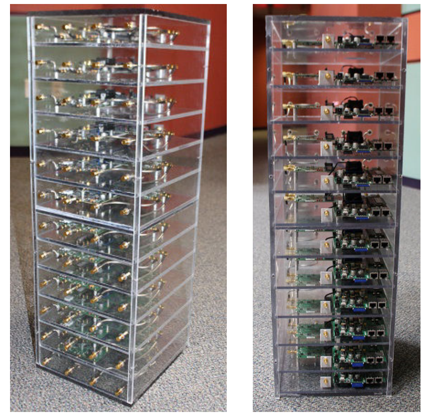
Building a many-antenna base station to function as a multi-purpose research platform is non-trivial. On one hand, ArgosV2 must have *real-time* capability, i.e., it must support streaming applications. Fast variation of real-world wireless channels, however, is a serious challenge for any MU-MIMO base station, and is the fundamental limiting factor for the performance of massive-MIMO. This is because the many-antenna base station must have accurate channel state information (CSI) to calculate the precoding vectors for each user. The presence of channel fading requires the base station to continuously collect the CSI to each user, within the channel coherence time, which can be as short as 100s of microseconds. As a result, the baseband processing for massive-MIMO must be done rapidly by ArgosV2, so that the base station and users can send downlink and uplink data transmission within the channel coherence time. On the other hand, as a research platform, ArgosV2 must support programmability of various massive-MIMO techniques such as conjugate beamforming, zero-forcing, MMSE, Tomlison-Harashima, etc. Depending on this massive-MIMO algorithm, often substantial portions of the baseband processing have to be done centrally, whereas other parts can be implemented in a distributed fashion for a performance and scalability gain [6]. Not surprisingly, realizing the real-time capability and programmability of ArgosV2 is quite challenging, requiring a careful and flexible design of the base station architecture which enables both centralized and distributed processing to accommodate the diverse plethora of emerging massive-MIMO techniques. In addition to the computational and hardware challenges facing a massive-MIMO research platform, we have found that the mechanical and form-factor design are critical components of a flexible, scalable, and usable system. Furthermore, most massive-MIMO techniques share a common requirement of time/frequency synchronization and channel estimation. However, these components are tedious and difficult to implement from scratch, thus we are developing a software framework, *ArgosLab*, to provide these key components out-of-the-box. Finally, to conduct experiments with real-world propagation environments and mobility, we have also developed a battery-powered compact mobile client, *ArgosMobile*.

2. ARGOSV2 DESIGN

The ArgosV2 platform design can be separated into three categories: 1) the mechanical design, 2) the hardware design, and 3) the software framework. Additionally, we have created ArgosMobile to facilitate real-world experimentation with massive-MIMO techniques.

2.1 Mechanical Design

From our previous experience in building a many-antenna base station, we have found the mechanical design and form-factor of ArgosV2 is critical for usability, reliability, scalability, resiliency, and performance. The basis of ArgosV2's mechanical design is a custom polycarbonate rack, shown in Figure 1. Each rack houses 12 WARPv3 boards on dado-style shelving, for a total of 48 radios. These radios are cabled to 48 panel-mount female SMA connectors spaced a half-wavelength apart at 2.4 GHz; this is the most compact 2D-array design which allows full performance with antennas mounted directly to the rack. The rack was carefully designed to present the SMA connectors on a 9.75 by 29.75 inch face, allowing racks to be stacked next to or on top of each other (using $1/4$ inch clips), while maintaining half-wavelength spacing between connectors across racks, both vertically and horizontally. Should different antenna spacing be required, perhaps to test a distributed-MIMO setup or an even more compact array for the 5 GHz band, this configuration enables cables to be easily attached to the panel-mount SMA connectors, allowing antennas to be placed anywhere. For easy-access, troubleshooting, assembly, and field-replacement, the dado-shelves can slide either forward or backward in the rack; all the shelves are held firmly in place by four full-length stops, which can be quickly removed to gain access to all of the WARP modules. This also allows shelves to be easily removed to be placed in remote locations to function as standalone APs, or as part of a distributed antenna system, for maximum flexibility.



(a) Front side (b) Back side

Figure 1: The ArgosV2 base station rack accommodates 12 WARP boards with 48 antennas; multiple racks can be easily connected using an ArgosHub to scale up the base station to support hundreds of antennas.

We also designed a polycarbonate ArgosHub [6], which uses similar dado-style shelving to house the clock, time-sync, power, and data distribution for up to 32 WARP modules (128 antennas). The hub was designed to be 19.75 inches wide with casters on the bottom, allowing two racks to attach flush to it, creating a single portable base station unit. Moreover, the modular design allows the base station to be easily scaled up with more racks, or split in to multiple small base stations, as well as quickly disassembled and reassembled for additional portability (such as for placement on inaccessible rooftops). Hubs can be easily daisy-chained or placed in a tree topology to support more radios.

Polycarbonate was chosen for its good impact resistance, as well as low cost and weight. While polycarbonate has relatively good anti-static properties, compared to acrylic, to ensure full protection against static discharge damage, we coated the racks and hub Lycron anti-static spray. Ventilation holes were strategically placed to promote airflow around the boards, and the racks were thermally tested to verify that the WARP boards do not overheat; we found that under continuous operation the temperatures of all boards stabilized below 50° C, which is well below the maximum operational temperature rating of 85° C.

This carefully planned mechanical design ensures that ArgosV2 is well-suited for diverse research environments, where usability, reliability, scalability, resiliency, and performance are critical.

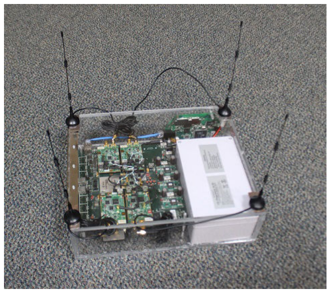


Figure 2: The autonomous ArgosMobile client is comprised of a 4-antenna WARP board, a battery, and an 802.11n bridge.

2.2 Hardware Design

ArgosV2 is based on the fundamental Argos system design described in [6]. This hierarchal modular design facilitates both distributed and centralized processing, which are required for massive-MIMO techniques. We leverage the new WARPv3 as the radio module to provide powerful, distributed, real-time processing at the radios. Additionally, most massive-MIMO techniques require tight time and frequency synchronization; we use ArgosHub to provide this synchronization, along with power and data distribution.

For frequency synchronization, ArgosHub utilizes 2 daisy-chained AD9523 clock distribution reference boards, each with a very low noise, accurate CrysTek CVHD-950 VCXO. Time synchronization is implemented using FPGA GPIO over twisted pair cabling. We chose a readily available 1300W server power supply to provide 12V DC power to the WARP modules. Finally, data distribution is achieved using a Netgear GS752TXS 48-port 1 GbE switch with 4 10GbE SFP+ ports, which provides 2 Gbps to each WARP module and up to 40 Gbps to the central controller, which may be comprised of a single server, an FPGA, or even a full compute cluster depending on performance requirements. While it would be advantageous to enable processing in the switch, as described in [6], it is not necessary for most research applications given the high-bandwidth of the switch, and would require an expensive custom design.

The ArgosV2 hardware design leverages off-the-shelf components to provide a powerful and flexible platform that is capable of accommodating the rigorous computational demands of emerging massive-MIMO techniques.

2.3 Software Framework

Massive-MIMO techniques share strict requirements for synchronization and CSI collection, and many use common precoders, which are time-consuming and difficult to implement efficiently. As part of our ongoing work to facilitate rapid prototyping and experimentation, we are designing ArgosLab, a software framework which works with ArgosV2 "out-of-the-box" to provide synchronization, reciprocity calibration, and channel estimation, as well as hardware accelerated linear precoding. Our goal is to enable researchers to develop and test massive-MIMO techniques in real-time, and in real-world environments, without having to spend months, or even years, developing the complex hardware and software required to enable such experimentation.

2.4 ArgosMobile

A critical component of ArgosV2 is the ArgosMobile, shown in Figure 2, as it enables experimentation in real-world propagation environments. ArgosMobile is an autonomous battery-powered mobile client that uses a WARP board to support up to 4 antennas, enabling client-side MIMO techniques. Additionally, ArgosMobile includes a standard 802.11 dual-band WiFi interface for out-of-band feedback and control; this feature is subtle, but crucial for accelerating development, as it allows testing of specific techniques without requiring a fully-functional network stack. The battery-life of the ArgosMobile shown is approximately 8 hours, though next generation uses batteries that are half the size. These new ArgosMobiles will be much smaller, lighter, and weather-resistant, which make them easier to deploy for outdoor and mobile experimentation.

3. CONCLUDING REMARKS

With the plethora of emerging work on massive-MIMO, it is critical for the community to have a research platform which supports rapid prototyping and experimental validation of proposed techniques. In order to fulfill this need, ArgosV2 holistically considers the hardware, software, and mechanical requirements to create a scalable, powerful, portable, and programmable design.

4. REFERENCES

[1] E. G. Larsson, F. Tufvesson, O. Edfors, and T. L. Marzetta, "Massive MIMO for Next Generation Wireless Systems," *arXiv:1304.6690 [cs.IT]*, 2013.

[2] T. Marzetta, "Noncooperative cellular wireless with unlimited numbers of base station antennas," *IEEE Trans. on Wireless Communications*, 2010.

[3] A. Ashikhmin. and T. Marzetta, "Pilot Contamination Precoding in Multi-cell Large Scale Antenna Systems," in *IEEE Int. Symp. Information Theory (ISIT)*, 2012.

[4] S. Mohammed and E. Larsson, "Per-Antenna Constant Envelope Precoding for Large Multi-User MIMO Systems," *IEEE Trans. Communications*, 2013.

[5] C. Shepard, N. Anand, and L. Zhong, "Practical Performance of MU-MIMO Precoding in Many-antenna Base Stations," in *Proc. ACM CellNet Workshop*, 2013.

[6] C. Shepard, H. Yu, N. Anand, E. Li, T. Marzetta, R. Yang, and L. Zhong, "Argos: Practical many-antenna base stations," in *Proc. ACM MobiCom*, 2012.

[7] Rice University Wireless Open Access Research Platform. `warp.rice.edu`.

[8] K. Tan, J. Zhang, J. Fang, H. Liu, Y. Ye, S. Wang, Y. Zhang, H. Wu, W. Wang, and G. M. Voelker, "Sora: High Performance Software Radio Using General Purpose Multi-core Processors," in *Proc. USENIX NSDI*, 2009.