Multi-hop MIMO Network Design Using WARP

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***Abstract*—Rice University's Wireless Open-Access Research Platform (WARP) is a platform designed to enable flexible research and prototyping of wireless networks at all layers. Specifically, WARP provides flexible processing resources tightly coupled to multiple radio interfaces, which can realize high-performance MIMO interfaces. This tight coupling of radio interfaces with local processing resources enables the construction of high-throughput, real-time physical layers. Further, the platform includes processors and network interfaces well-suited to implementing and evaluating novel protocols at the medium access control (MAC) and higher networking layers. In this demonstration, we will highlight each of these capabilities.**

I. Introduction

We present a comprehensive demonstration of the Rice University Wireless Open-Access Research Platform (WARP), a highly capable, scalable and extensible platform for advanced wireless networking research.

WARP was designed from the ground up to provide the resources required to implement advanced wireless algorithms at all layers of the networking stack. The platform consists of a number of key components. First, it is built around custom hardware designs, integrating FPGA-based processing resources with real radio interfaces. Second, the platform is supported by custom modules which ease the use of the hardware's various processing and peripheral resources. Third, these platform support modules are used to construct a variety of research applications, including real-time implementations of physical and MAC layers. Finally, every component of the platform design is freely available via the WARP repository under a standard open-source license [1]. WARP's integration of local processing resources, wireless interfaces and integrated platform support is a unique combination, setting it apart from other platforms whose resources are tailored towards just physical layer prototyping [2], MAC protocols [3] or routing protocol research [4].

Our demonstration of WARP is intended to illustrate three key capabilities. First, we will show the operation of multiple-input multiple-output (MIMO) physical layer transceivers, working in real-time over the air. Second, we will demonstrate a four-node WARP network implementing a MIMO multi-hop MAC protocol. This network will enable an end-to-end link between two PCs, where every packet traverses two relay nodes. Finally we will demonstrate WARP's ability to gather experimental data in real-time at every layer of our custom network stack.

This project is funded by NSF grants ANI-0325971, EIA-0224458 and EIA-0321266. Special thanks to Xilinx for their ongoing support throughout this project.

II. Physical Layer Design

One of the primary goals of WARP is the ability to implement custom algorithms at all layers of the network stack. Providing the processing resources to implement custom high-performance physical layers was a critical design requirement. The WARP design meets this requirement using an FPGA as the main processor. The FPGA provides both the flexible processing resources required for real-time physical layer design and the peripheral connectivity to couple the physical layer processing to real radio interfaces.

We have implemented two MIMO OFDM transceivers which run in real-time. The first supports both SISO and two-antenna spatially multiplexed MIMO links. The second implements an OFDM version of Alamouti's transmit diversity scheme [5], utilizing two antennas at each node. Both transceivers are implemented in the FPGA fabric using Xilinx's System Generator design flow [6], and both models are available open-source in the WARP repository [1]. The transceivers operate at a bandwidth of 10 MHz (compared to 20MHz for IEEE 802.11a/g) and are capable of datarates ranging from 12 Mbps (using QPSK) to 36 Mbps (using 64-QAM). We will demonstrate SISO and MIMO links between WARP nodes as part of the multi-hop network described below.

III. Multi-hop MAC Layer Design

We have implemented two standard random-access MAC protocols, both available in the WARP repository. The first is based on ALOHA [7]; the second is an extension which includes carrier sensing multiple access (CSMA). Both implementations are built on top of WARPMAC, our custom MAC framework [8]. WARPMAC provides an abstraction between the custom OFDM physical layers implemented in the FPGA fabric and custom MAC protocols implemented in C in the FPGA's processor cores. This framework is designed to jump start custom MAC protocol implementations by masking many of the details involved in controlling the physical layer and WARP radio interfaces. WARPMAC is also designed to reduce overhead by minimizing the latency of MAC processing. For example, our WARPMAC-based CSMA implementation is capable of sustaining an over-the-air link with end-to-end throughput of 8.5 Mbps when built on a 12 Mbps PHY.

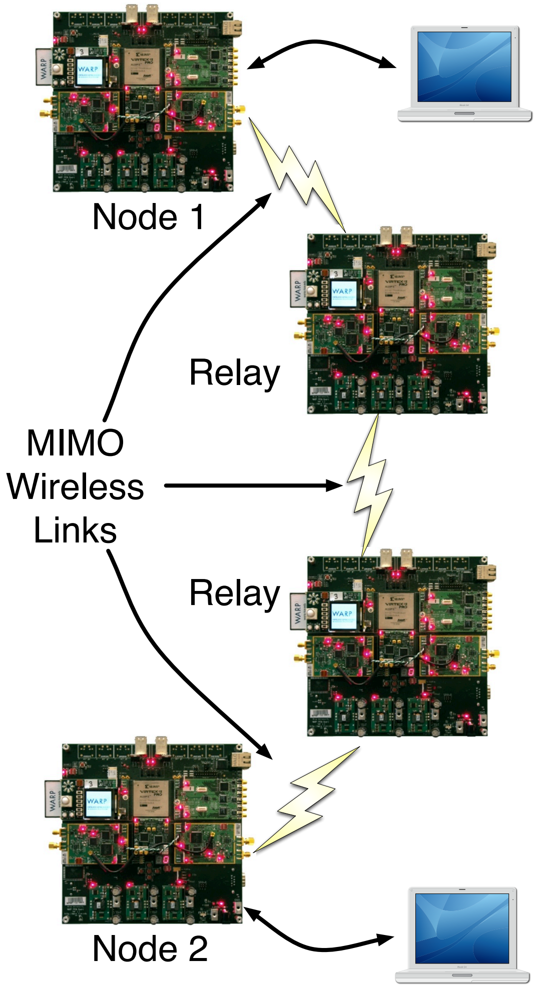

Fig. 1. Multi-hop MIMO wireless network demonstration setup

We have recently extended our basic CSMA MAC implementation to realize multi-hop topologies. In these topologies, two WARP nodes communicate with the help of relay nodes which forward packets at the MAC layer. Our multi-hop protocol takes advantage of WARP's programmability at the PHY and MAC layers. For example, in one mode the source node starts a timeout timer after sending a packet. If it observes a busy medium shortly after sending its packet, the protocol pauses the timer to check whether it has just overheard the relay re-transmitting the data packet. If so, the source infers an ACK and prepares its next transmission. If the source fails to sense a busy medium, it can infer a failure and attempt a retransmission. This technique exploits WARP's programability at every layer, allowing coordination between the MAC and the carrier sensing mechanism in the PHY.

Our demonstration of the WARP multi-hop MAC design, illustrated in Figure 1, will utilize four WARP nodes. Two nodes will act as MAC-layer relays. Two additional nodes will communicate with one another via these relays with traffic generated by a pair of laptop computers. Each computer will send a video file to the other via a standard UDP stream. With both streams running concurrently, every WARP node will constantly contend for the medium to maintain the flow in both directions. Our multi-hop CSMA-based MAC protocol handles this situation well, enabling both streams to be sustained efficiently.

IV. Performance Evaluation

Our final demonstration will illustrate how custom wireless designs running on WARP can be evaluated using detailed measurements taken at every network layer. Our custom MAC and PHY implementations track a variety of measurements in real-time. The PHY tracks metrics like channel quality per-packet, even per-subcarrier, and historical medium utilization. The MAC records metrics like numbers of good and bad packets received and retransmission attempts. All of these observations can be extracted from each node without interfering with the operation of the wireless links. We will demonstrate this capability, displaying various MAC and PHY performance metrics from each node in the multi-hop network.

V. Demo Requirements

We will provide all the WARP and computing hardware necessary for these demonstrations. We will require only table space, power and an hour of setup time. If it is available, we would also use space to hang a poster near the demo setup.

References

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