Demonstration Abstract: WARP – A Flexible Platform for Clean-Slate Wireless Medium Access Protocol Design

Ahmed Khattab, Joseph Camp, Chris Hunter, Patrick Murphy,
Ashutosh Sabharwal and Edward W. Knightly
{*khattab,camp,chunter,murphpo,ashu,knightly*}*@rice.edu*
ECE Department, Rice University, Houston, TX, USA

The flexible interface between the medium access layer and the custom physical layer of the Rice University Wireless Open-Access Research Platform (WARP) provides a high performance research tool for clean-slate cross layer designs. As we target a community platform, we have implemented various basic PHY and MAC technologies over WARP. Moreover, we are implementing cross-layer schemes such as rate adaptation and cross-layer MIMO MAC protocols. In this demo, we demonstrate the flexibility of the interaction between the the WARP PHY and MAC layers by showing the capability to instantaneously change the modulation scheme, disabling/enabling MAC features such as carrier sensing or RTS/CTS 4-way handshake, and different multi-rate schemes.

I. WARP Overview

Wireless open-Access Research Platform (WARP) [1] is a programmable wireless research tool that is both scalable and extensible. The custom design of the WARP physical (PHY) layer is tailored to the needs of high-performance wireless communications. While the GNU Radio and the USRP are limited to narrow band applications, WARP is designed to support wide band communication designs. The flexible interrupt-driven interface between the PHY and the medium access control (MAC) layers allows for the development and performance evaluation of a large class of cross-layer designed protocols. WARP provides a general environment for a clean-slate MAC/PHY development unlike other platforms which rely on off-the-shelf IEEE 802.11 cards, which limit experimentation only to modifications of existing standards.

The main objective of WARP is to provide the community with such a flexible wireless research tool. At Rice University, we developed the fundamental building blocks of the PHY and MAC layers for a wide range of wireless systems. The WARP on-line open-access repository [1] provides a central archive of the models and source code of these fundamental blocks, as well as other support packages. More than ten wireless research institutions have purchased WARP hardware for their own research.

II. WARP Hardware Description

Figure 1 depicts the WARP hardware. The main components of hardware are (for more details see [6]):

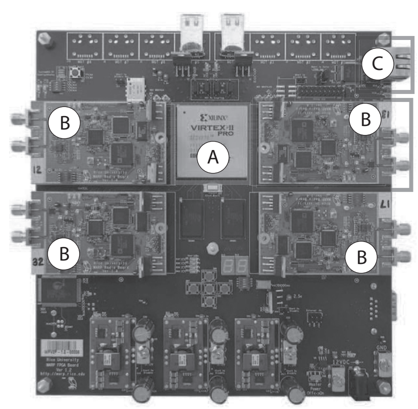

Figure 1: MIMO-capable WARP board.

(A) Xilinx Virtex-II Pro FPGA board. The FPGA includes a large number of embedded programmable logic blocks for real-time DSP applications as well as two PowerPC 405 cores. The C implementations of MAC protocols interact with the PHY processing units and supporting peripherals in the FPGA fabric. WARP FPGA board has has 4 general purpose daughtercard slots. In addition to the FPGA board, we have designed radio, analog I/O, and video daughtercard boards.

(B) MIMO-capable radios. The custom designed WARP radio boards are capable of targeting both the 2.4 GHz and 5 GHz ISM bands. The dual-band radio transceiver is intended for wide band applications, such as OFDM, with a bandwidth up to 40 MHz. Up to four radios can be mounted on a single WARP board to enable 4×4 MIMO systems.

(C) 10/100 Ethernet port. Serves as the interface between the board and the wired internet.

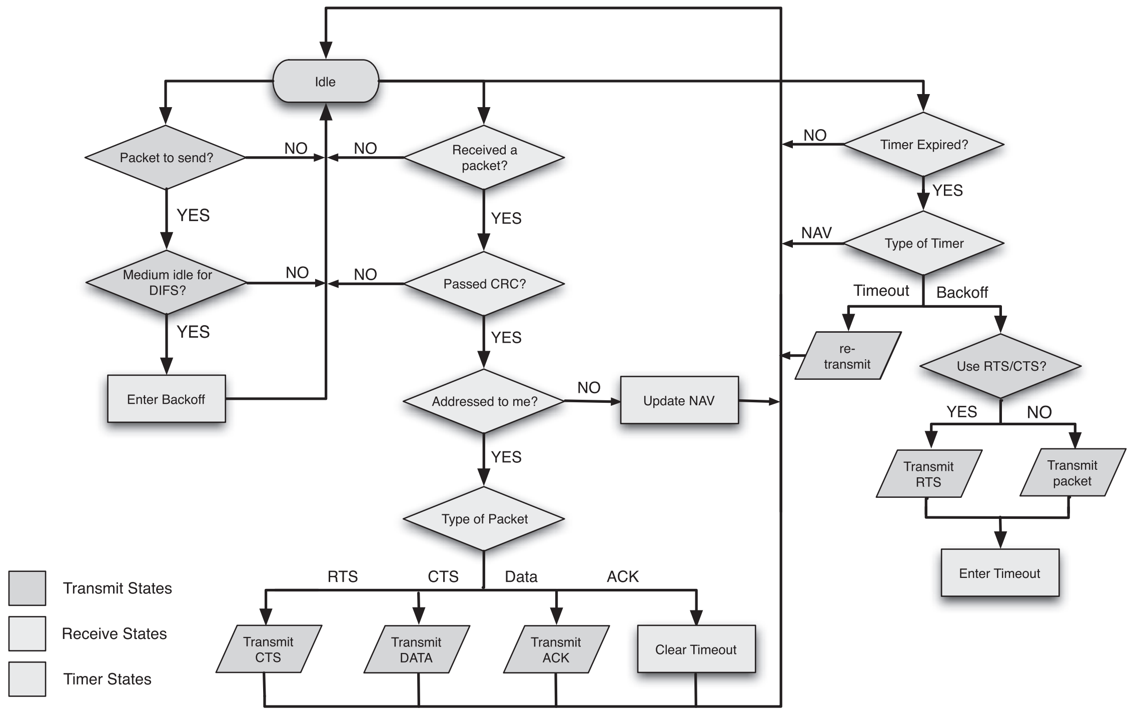

Figure 2: State diagram of the CSMA/CA protocol with 4-way RTS/CTS handshake.

III. WARP Implementations

Physical Layer Implementations. WARP PHY implementation is based on custom OFDM transceivers. Even though the transceiver design is intended for IEEE 802.11a/b/g/n applications, the modular design of the radio allows for other interfaces. Advanced Multiple Input Multiple Output (MIMO) communication systems can be realized by tuning different radios to the same frequency channel. 2×2 Alamouti and 2×2 spatial multiplexing systems, with antenna selection capability, are currently implemented.

MAC Protocol Implementations. MAC protocols can be rapidly implemented and tested using WARP. The state machine of the protocol is developed in C code then complied for the PowerPC core within the FPGA. Once downloaded on the PowerPC, the MAC protocol directly communicates with the hardware peripherals. To facilitate the development of new MAC protocols on WARP, we have created a flexible interface that provides user-level access to parameters common to most physical layers [4]. Hence, WARP provids seamless flexibility in the development of cross-layer designed protocols such as SNR-based rate adaptation, advanced MIMO MAC protocols with beamforming and smart antenna selection features.

We have implemented different basic medium access protocols such as ALOHA, basic Carrier Sense Multiple Access (CSMA), Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA), and Orthogonal Frequency Division Multiple Access (OFDMA) scheduled access. As shown in Figure 2, WARP CSMA/CA implementation provides the main mechanisms of the IEEE 802.11 standard (such as physical and virtual carrier sensing, four-way handshaking, and correct packet reception acknowledgement mechanisms). However, our implementation is not yet standard-compliment due to differences in the frame format. As a community platform, the source code of the aforementioned MAC implementations are available on the WARP website in the form of central repository [1].

Apart from the basic protocol, we have also implemented mechanisms such as multi-hop forwarding and rate adaptation schemes. Unlike off-the-shelf card, both loss-based and SNR-based rate adaptation can be implemented in WARP. WARP PHY/MAC interface provides seamless cross-layer accessability and controllability. Hence, SNR-based rate adaptation, which require instantaneous channel quality reporting from the physical layer to the MAC layer, is easily realized over WARP. The MAC protocol maps the received signal strength and decides the appropriate transmission rate. Different transmission rates are realized via changing the modulation scheme. Figure 3 depicts the signal strength map of BPSK, QPSK, and 16-QAM modulation schemes used for the SNR-based rate adaptation in WARP MAC.

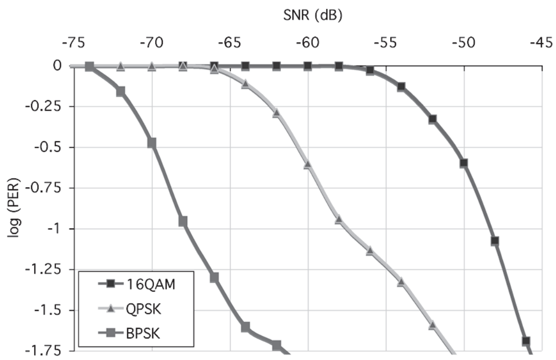

Figure 3: Packet error rates for different WARP modulation schemes.

IV. WARP in Operational Networks

Due to its capabilities, the WARP hardware is planned to serve as a wireless backhaul tier in our operational multi-tier mesh access network [2] shown in Figure 4. Rice University in collaboration with Technology For All (TFA), a non-profit organization, has deployed and operate a wireless mesh network that provides wireless access to over 3,000 users spanning approximately 3 square kilometers in Houston, Texas. The Rice/TFA mesh deployment is a three-tier network: access tier, backhaul tier and capacity injection tier. Currently, nodes employ off-the-shelf IEEE 802.11 cards for all tiers. This limits the research applications carried over the network to measurements, mobility, routing, localization, VoIP, AP association, medical sensing studies. In the near future, WARP will be used to provide both backhaul tier connectivity and capacity injection tier. In this case, WARP boards are called Transit Access Points (TAPs) [3]. Commercial IEEE 802.11 cards will still be used for user access tier. Integrating the WARP/TAPs platform with Rice/TFA network will pave the way for a clean-slate mesh protocol design and performance evaluation [5]. Examples include multi-channel, multi-radio, MIMO, and counter starvation medium access protocols.

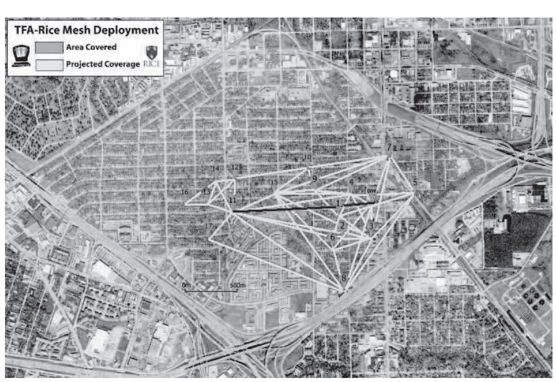

Figure 4: Connectivity map of Rice/TFA operational mesh deployment.

V. Demo Set-up

In this demonstration, we illustrate the difference in the performance of basic PHY and MAC implementations as well as cross-layer rate-adaptation schemes. Figure 5 illustrates the demonstration set up.

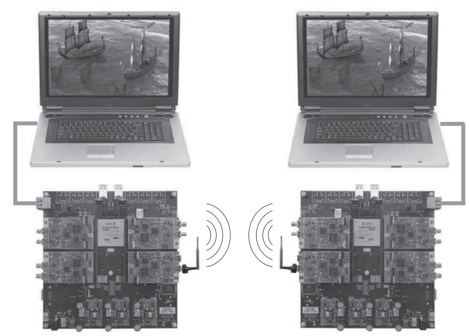

Figure 5: Demo Set-up.

We perform video streaming between two laptops each attached to a WARP board. The board attached to the streaming source transmits whatever is present at its Ethernet port via the wireless medium. In order to illustrate the performance difference of various schemes we use *iperf* to generate a UDP flow at the transmitting node. At the receiver, we show the received UDP throughput. We use the WARP user interface to enable/disable carrier sensing or RTS/CTS handshake, and change the underlying modulation scheme, and finally invoke different rate adaptation mechanism including both SNR-based rate adaptation as well as loss-based auto-rate. In each case, we show the impact on the realized throughput.

References

[1] http://warp.rice.edu/.

[2] http://tfa.rice.edu/.

[3] http://taps.rice.edu/.

[4] C. Hunter, J. Camp, P. Murphy, A. Sabharwal, and C. Dick. A flexible framework for wireless medium access protocols. In *Asilomar*, November 2006.

[5] R. Karrer, A. Sabharwal, and E. Knightly. Enabling large-scale wireless broadband: the case for TAPs. In *Proceedings of HotNets-II*, November 2003.

[6] P. Murphy, A. Sabharwal, and B. Aazhang. Design of WARP: Wireless open-access research platform. In *European Signal Processing Conference*, June 2006.