# Demo: An Open-Source Development Platform for Long-Range UHF-Connected WiFi Hotspots

Ryan E. Guerra, Narendra Anand, and Edward W. Knightly
Rice University, Houston, TX, USA
{war,nanand,knightly}@rice.edu

## ABSTRACT

We present a real-time software-defined radio (SDR) platform for prototyping and measuring the performance of broadband UHF radio networks operating over long distances with point-to-multipoint (PTMP) non-line-of-sight (NLOS) networks. Enabled by the Wideband UHF Radio Card (WURC), a custom high-power and frequency-flexible radio transceiver daughter-card for FPGA-based digital basebands, the 802.11 DCF-like MAC and PHY implementation is completely open source. We demonstrate a long-range PTMP NLOS network bonding several of the white space television channels available in Maui, Hawaii. Off-the-shelf client devices can use this network via 802.11a/g links implemented with the same SDR framework. The multi-carrier channel estimates and real-time MAC statistics of connected nodes in UHF and 2.4 GHz are recorded and displayed in real-time, demonstrating an unprecedented amount of flexibility in unlicensed frequency bands, enabling real-time TV-band cognitive networks and small-cell research deployments.

A demonstration video is available at the following link: `http://youtu.be/dTOJHRICklQ`.

## Categories and Subject Descriptors

C.2.1 [**Computer-Communication Networks**]: Network Architecture and Design—*Wireless Communication*

## Keywords

Last-Mile, UHF, Software-Defined Radio, MAC, Channel Measurement, WiFi Hotspot, Small Cell


*MobiCom'14,* September 7-11, 2014, Maui, Hawaii, USA.

ACM 978-1-4503-2783-1/14/09
http://dx.doi.org/10.1145/2639108.2641753.

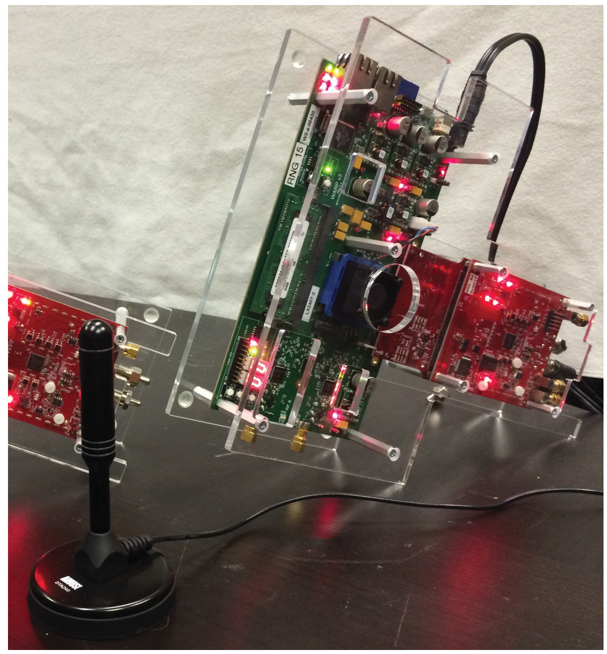


**Figure 1: Mobile network node with WARPv3 digital baseband and attached WURC daughtercard with small UHF antenna.**

## 1. INTRODUCTION

The applications and capabilities of cognitive radio networks have increased greatly now that unlicensed devices may operate on unoccupied UHF channels (50-800 MHz) in many countries around the world [6]. The excellent propagation characteristics of the UHF band enable new applications for unlicensed networks in promising areas like machine-to-machine communications (M2M), rural last-mile broadband, and smart-utility backhaul [6].

Efficient design, deployment, and operation of these networks depend on the development of new technologies and techniques for increasing spectral efficiency [5], enabling coexistence with other unlicensed devices, and aggressively detecting and utilizing spectrum-sharing opportunities.

While the integration and flexibility of wireless components has been increasing to the point that highly-configurable radio front-ends are available, to date there has been no highly-configurable real-time reference design available for researchers interested in development and prototyping MAC and higher-layer systems in the UHF band, particularly with respect to high-power, high-bandwidth applications.

With that in mind, we designed WURC as a complete high-power analog front-end for state-of-the-art Software-Define Radio (SDR) that can enable experimental wireless development at long-range with a completely open MAC and PHY implementation. In Figure 1, we show a single network node consisting of a digital baseband build on the WARPv3 platform [2] and the WURC analog daughtercard with a small UHF antenna. This forms the basic building-block of our demonstration network.

## 2. REAL-TIME UHF BACKHAUL

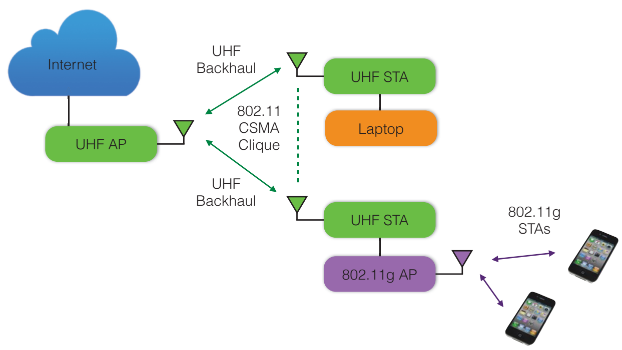


**Figure 2: Diagram of the demo network topology.**

A previous system utilizing the WURC platform [4] focused on physical-layer research and development, relying on off-line processing of captured RF samples [3] to enable rapid testing and iteration on different waveforms and complex MIMO precoding or decoding schemes. Cognitive radio is getting its first large-scale test case in the UHF bands The integration of the WURC platform with the WARP 802.11a/g [1] reference design enables long-range, non-line-of-sight (NLOS) UHF links with high bandwidth.

A number of enabling contributions were developed for the WURC platform:

- a broadband power-transfer network for the UHF power amplification chain to create a relatively flat frequency response from 470-698 MHz;
- a new automatic gain control (AGC) loop developed in HDL that can meet 802.11g timing requirements for packet detection and receive gain convergence without an external power detector like the native WARPv3 RF chains;
- modifications to the 802.11a/g reference design [1] to enable variable-rate channel bandwidths of 5, 10 and 20 MHz as specified in the 802.11-2012 standard and to allow transmissions to fit within a single North American UHF channel of 6 MHz, or multiple channels with wider channel bandwidth;
- an automated calibration and characterization framework to correct analog impairments and process variation across many fabricated modules;
- integration, driver development, and physical layer tuning to support the new hardware with simple APIs that let the researcher rapidly prototype their system.

Additional details about the component implementation and an example of physical-later applications of the WURC platform are available in [5].

In this demo, we present a real-time network composed of at least three WURC-enabled SDR nodes operating on free broadcast television channels available in the Maui, Hawaii area. An experimental license has been obtained to operate on these unused UHF channels.

In the demonstration topology, a wired internet connection is shared from the UHF AP to STA nodes (green nodes) via a Layer 2 wireless bridge following the 802.11 Distributed Coordination Function (DCF). Wireless client devices owned by conference attendees can share this connection further by connecting to an open 802.11a/g network hosted by another WARP board connected via a layer 2 ethernet bridge. The broadcast SSID of this hotspot is "Rice-SuperWiFi."

This demonstration network is open source and programable at all layers, allowing the researcher to modify a system of interest and test on an operational, large-scale network if desired. The UHF reference design has been verified to operate at distances up to 1 kilometer in an outdoor, point-to-multipoint, NLOS network, as well as in an indoor, NLOS, multi-floor infrastructure deployment spanning the coverage areas of tens of WiFi access points.

In addition, the power of the open platform is demonstrated by measuring the channel state information and real-time MAC parameters of connected clients at both the UHF and WiFi nodes in real-time. Users of the network are able to browse the internet at broadband speeds while the monitoring system shows their network actions and channel statistics.

## 3. FUTURE WORK FOR UHF NETWORKS

The development and release of the WURC analog front-end enables a number of different research tracks:

**Small-Cell Research**. The presented reference design has been verified to operate at broadband speeds up to 1 kilometer NLOS in a point-to-multipoint outdoor deployment as well as indoors with multi-floor NLOS coverage from a single access point. While 2.4 GHz WiFi networks have been deployed in outdoor scenarios, they are severely limited by path loss and shadowing, whereas unlicensed devices in the UHF band benefit from an extended practical range that is realized by WURC. This enables at-scale deployments of open small-cell networks without the expense of LTE or WiMAX equipment and a completely open network stack. Interoperability with commodity equipment and access to queuing and scheduling at each point in the wireless network enables a host of possible quality-of-service applications.

**UHF-Band MAC**. Network topologies and channel availability in the UHF bands will be significantly different than the short-range WLANs envisioned by 802.11ac and 802.11af, while proposed solutions like 802.22 or LTE in UHF-bands represent significant investment in infrastructure and network coordination. The design of efficient MAC protocols that adapt to the different network topologies in UHF, coordinate spectrum sensing to identify spectrum reuse opportunities, or coordinate spectral usage through spectrum databases is currently a hot topic in the wireless research community. The demonstrated reference design allows rapid testing of new protocols by providing an out-of-the-box solution that can serve as a building-block.

**Interference Mitigation and Coexistence**. Cognitive radio networks in the UHF band will be operating in an environment with many interferers, both primary spectrum users (DTV transmitter and microphones) and secondary spectrum users (unlicensed UHF-band devices). MIMO beamforming and interference cancellation techniques can be used to mitigate both primary-to-secondary user interferences as well as secondary-to-primary user interference. WURC enables operational network topologies and environmental measurements at large scale and in true, outdoor environments, allowing researchers to prototype and test their systems.

## Acknowledgments

This research was supported by NSF grants CNS-1314822, CNS-1126478, CNS-1012831, and a grant from Cisco Systems, Inc.

## 4. REFERENCES

[1] Mango 802.11 reference design. [online]. Available at: `http://mangocomm.com/802.11`.

[2] Rice University WARP project. Available at: `http://warp.rice.edu`.

[3] MobiCom demonstration video preview, June 2014. Available at: `http://youtu.be/dTOJHRICklQ`.

[4] WURC documentation, June 2014. Available at: `http://www.volowireless.com/products/WURC`.

[5] N. Anand, R. Guerra, and E. Knightly. The Case for UHF-Band MU-MIMO. In *Proc. ACM MobiCom*, Maui, HI, Aug. 2014.

[6] A. Flores, R. Guerra, E. Knightly, P. Ecclesine, and S. Pandey. IEEE 802.11af: A Standard for TV White Space Spectrum Sharing. *IEEE Communications Magazine*, 2013. 51(10):92-100.