Advances in Wireless M2M and IoT: Rapid SDR-prototyping of IEEE 802.11ah

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***Abstract*—We propose demonstrating an IEEE 802.11ah wireless local area network (WLAN) prototype that is configured as a self-contained machine-2-machine (M2M) wireless sensor system. Because the IEEE 802.11ah protocol standardization is under way, no commercial-off-the-shelf (COTS) IEEE 802.11ah Wi-Fi product is available yet. However, the proposed prototype has the potential to solve this issue and allows an over-the-air protocol performance assessment. A software defined radio (SDR) platform is developed, that consists of universal software radio peripheral (USRP) devices combined with radio frequency (RF) daughter-boards operating at the 900 MHz ISM-band. Additionally, the 2×2 multiple-input multiple-output (MIMO) orthogonal frequency division multiplexing (OFDM) operation is realized, which requires modifications on the PHY implementation. This demo provides a practical and cost-efficient research platform for the upcoming IEEE 802.11ah WLAN and its use in M2M and Internet of Things (IoT) wireless long-range access networks.**

***Index Terms*—WLAN, M2M, IoT, IEEE 802.11ah, sub-1 GHz, Wi-Fi sensor.**

I. Introduction

The IEEE 802.11ah Task Group (TG) is under way to standardize wireless local area networks (WLANs) that will use carrier frequencies in the 900 MHz industry, scientific, and medical (ISM) bands. These so-called sub-1 GHz (S1G) WLANs, operating in the ultra high frequency (UHF) band, will offer unique features, such as longer outdoor coverage range and energy consumption reduction to enable so-called *Wi-Fi sensor* networks. Additionally, IEEE 802.11ah WLAN will be an alternative to IEEE 802.15 short-range sensor systems and will enable cost-efficient machine-to-machine (M2M) and Internet of Things (IoT) wireless access networks.

Compared to the upcoming IEEE 802.11af standard, both WLAN protocols aim to exploit the increased penetration of wireless signals at lower frequencies. However, IEEE 802.11af requires a set of additional architectural elements, including spectrum a data base and a location server to enable TV white space (TVWS) access [1] . Hence, the IEEE 802.11ah WLAN is a cost-efficient and practical solution for long-range short-burst data traffic in the S1G ISM band. A challenge with the IEEE 802.11ah WLAN is the limited channel bandwidth of 1 MHz (Japanese region). The use of an IEEE 802.11ah WLAN prototype would be beneficial to evaluate the bandwidth constraints. To meet this demand the creation of a software-based WLAN is an alternative to chip-based WLANs, in which new physical layer (PHY) functions and media access control (MAC) schemes can be implemented and evaluated.

We propose a multiple-input multiple-output (MIMO) orthogonal frequency division multiplexing (OFDM) S1G WLAN that uses software defined radio (SDR) in combination with open-software GNU Radio [2] . We argue that the proposed system has many advantages. Firstly, it is simple and cost-efficient, because the required S1G radio frequency RF front-end is realized using universal software radio peripheral (USRP). Secondly, it is modular, because RF components can be changed to different frequencies and the required software can be extended. These advantages come with a cost in performance limitations, because almost all system calculations are executed in software on a host (a personal computer) and therefore cannot be as fast as customized field programmable gate array (FPGA) boards or chip-based WLANs.

Testing platforms for wireless communication, and in particular for MIMO broadband systems, have been widely proposed for cellular systems and WLANs operating at 2.4 GHz or higher carrier frequencies. In [3] the authors propose an SDR system using USRP to evaluate hierarchical modulation schemes at 2.6 GHz to avoid interference from WLAN systems operating at 2.4 GHz. Another example of using SDRs is in [4] where a real-time system using USRP [5] and GNU Radio [6] operating at 2.4 GHz is proposed. The motivation to use USRP in comparison with other small form factor SDRs is that the USRP has reliable and better user support and allows the use of free open-source software. In [7] the authors propose a 4×4 MIMO-OFDM platform by using FPGAs operating at 902-928 MHz band. However, the motivation was to apply the 915 MHz band to avoid the highly congested 2.4 GHz band to conduct measurement campaigns including three different outdoor locations. However no results were reported on how to design a MIMO-OFDM system operating at narrow-bandwidths.

The IEEE 802.11ah TG aims to standardize a long-range WLAN system that will allow up to 1 km range at moderate data rate up to 100 kbps [8]. The modulation scheme proposed supports multi-antenna systems and path loss models for longer outdoor range, robustness and energy efficiency. To the best of our knowledge there has been no reports on IEEE 802.11ah prototype WLANs.

II. Proposed IEEE 802.11ah WLAN Platform

We propose a low-cost solution that allows a simple operation of MIMO-OFDM functions in a wireless hardware using a configurable software radio platform. Here, we propose using open-source software to design a generic platform, that, is independent from the carrier frequency f_c and allows MIMO-OFDM operation in narrow-band wireless systems, e.g., 1 MHz channel bandwidth. We realize a *real-time* MIMO-OFDM encoding/decoding which is state-of-the-art in other platforms to evaluate wireless transmissions over-the-air. However, real-time encoding schemes require high performance hardware due to exhaustive FFT/IFFT operations.

We selected the USRP 1 which supports two internal RF boards without the requirement of having an external clock [5]. We setup the USRP 1 with two SBX daughter-boards operating at $f_c = 923$ MHz. The SBX boards cover a frequency band between 400 MHz - 4.4 GHz, with a nominal noise figure of 4 dB. Transmit power can be selected anywhere between 30 mW - 100 mW. Fortunately, SBX supports the sub-1 GHz band so that this board is useful for transmitting a MIMO-OFDM modulated signal at $f_c = 923$ MHz. We found that the I/O-control of the SBX boards requires significant changes in the serial USRP interface, which we implemented as a new *USRP Hardware Driver* (UHD) library for SBX support at $f_c = 923$ MHz. We added the library to support two SBX boards configured as 2×2 MIMO multi-antenna system in a single USRP. In Table I the test parameters are presented, which we used in our wireless M2M setup.

TABLE I
Sub-1 GHz WLAN Performance Test Parameter

System parameter	Value
Modulation	OFDM
Spatial diversity	SISO, 2×2 MIMO
Carrier frequency, f_c	923 MHz
Channel bandwidth, B	1 MHz
Antenna (omni-directional)	VERT 900 (860 - 980 MHz)
Traffic pattern	M2M sensing data, UDP, TCP
Traffic duration	short burst
Sending power, Tx_{power}	0 dBm (default)
Carrier sense threshold	-80dBm, CSMA/CA
slot time	10 ms (default)
SIFS, DIFS	10 ms, 30 ms (default)
MCS (SISO)	0, 1, 2, 3, 4
MCS (2×2 MIMO, beamform off)	8, 9, 10, 11, 12

Fig. 1 illustrates the demo setup. The setup consists of an IEEE 802.11ah sender and receiver node. At the sender node an external USB M2M sensor is attached. The M2M sensor reports variations in temperature and humidity with a sending interval $T_s = 1$ s, with 100 B packet size. Our platform is installed with Ubuntu Linux, version 11.04, running on personal computers with two Pentium-4 processors. We found that GNU Radio, version 3.2.2, is a valid compromise between supporting the applied multi-antenna MIMO-OFDM software framework [9] and the required UHD driver and SBX interface. The IEEE 802.11ah prototype provides a helpful research platform for the upcoming IEEE 802.11ah WLAN protocol amendment. It is practical, cost-efficient, and easy to install; thus, it is argued that the prototype has a significant merit for the research community. For instance, the main challenge of IEEE 802.11ah WLAN is the interference caused by of out-of-band (OOB) emissions. Because of the presence of other wireless systems that coexist in the S1G narrow-band, such as RFID and IEEE 802.15.4 devices, OOB suppression is required, similar to the challenges in IEEE 802.22 or IEEE 802.11af systems [1]. The prototype can be useful in the assessment of OOB emissions and proposed remedies, including infinite impulse response (IIR) filtering [10].

III. Demonstration details

A. Demo scope

The scope of the demo is twofold. Firstly, with the help of the demo wireless experts can easily engage in discussions of the usefulness of the new IEEE 802.11ah WLAN protocol. IEEE 802.11ah is an alternative to IEEE 802.15.4 protocols. The new IEEE 802.11ah WLAN protocol features are useful for M2M and IoT applications, such as sensor data exchange. Secondly, due to the fact that IEEE 802.11ah off-the-shelf products are not available yet, a discussion of other potential prototypes and testbed platforms can further help to promote the applicability of IEEE 802.11ah, e.g., in M2M and IoT wireless testbeds. The proposed IEEE 802.11ah demo setup transmits sensing data, such as temperature and humidity meter information, as a form of M2M traffic over-the-air between an IEEE 802.11ah sender and receiver node. Fig. 2 shows a

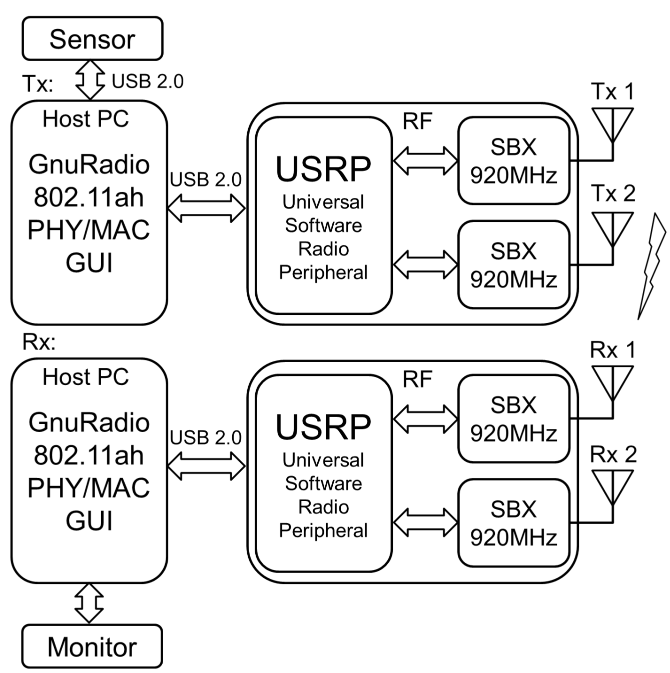

Fig. 1. M2M setup (Tx and Rx) of sub-1 GHz WLAN with sensor.

photograph of the proposed demo setup, showing two laptops and two USRPs.

B. Equipment, space and setup time

The IEEE 802.11ah prototype demo requires the following equipment that is planned to be brought to the conference:

1) 2 x laptop PCs. The first laptop shows the real-time monitored transmission performance of IEEE 802.11ah (I/Q chart, MIMO channel gain, MCS rate). The second laptop displays the real-time report of the USB temperature sensor, as an M2M application scenario. A separate programmed GUI is used to show the temperature and humidity data to the LCN demo audience.
2) 2 x USRP units (Tx/Rx), equipped with SBX daughterboards. The USRPs are connected via wired cables to mitigate wireless interference. In addition, wired connection between the USRPs is required not to violate any radio laws, when using un-certified radio equipment. However, the wired connection allows a discussion of selected MCS rates and 2×2 MIMO real-time channel gain display during the demo.
3) A third laptop is planned to be brought to show a recorded video of the entire setup (if needed).
4) USB cables, power connectors.

The IEEE 802.11ah demo setup (laptops, USRPs) are located on a table (2×2 m). A power supply with 6 power sockets is required. Setup time is estimated to be 1 hour, including time to transport the equipment to the LCN demo desk. The demo is self-contained and does not require any Internet access. Alternatively, a recorded video of the entire running prototype setup can be shown instead, including a visualization of a recorded batch-file of the M2M sensor traffic (wireless transmission of temperature and humidity data from the IEEE 802.11ah WLAN sender node to the receiver node).

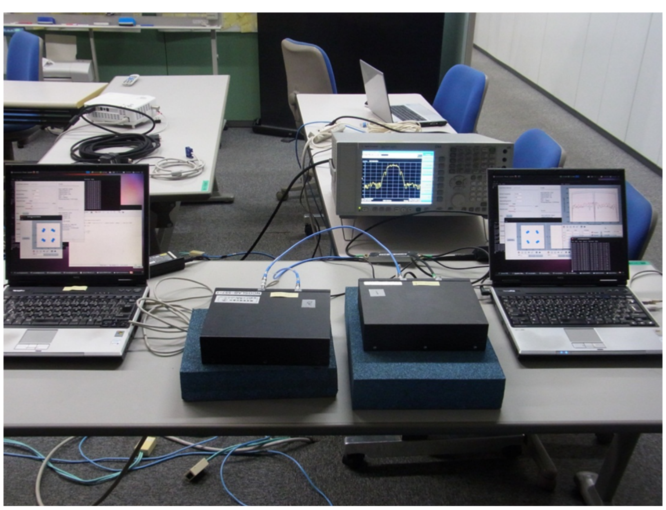

Fig. 2. Photograph of the proposed IEEE 802.11ah WLAN demo setup.

IV. Conclusions

The upcoming IEEE 802.11ah protocol offers advanced protocol features that are beneficial for future M2M and IoT wireless access networks. The new WLAN offers moderate data rates at longer range compared to IEEE 802.15.4 systems. Thus, new service value to recent sensing applications can be added in a cost-efficient way. The proposed IEEE 802.11ah prototype demonstrates the applicability of the new WLAN protocol for sensor applications because no COTS IEEE 802.11ah Wi-Fi products are available yet. An SDR-prototyping was proposed that uses USRP and GNU Radio to evaluate the IEEE 802.11ah WLAN performance over-the-air operating at the sub-1 GHz ISM-band. The $2{\times}2$ MIMO-OFDM operation was implemented to examine the wireless transmission boundaries of a narrow-band WLAN. The prototype provides a practical and cost-efficient opportunity to test the upcoming IEEE 802.11ah WLAN standard and its usefulness for M2M and IoT long-range access network deployments.

In this demonstration we will show the applicability of IEEE 802.11ah WPAN protocol for M2M sensing applications. We will demonstrate a self-contained wireless M2M sensor data scenario in a multi-node IEEE 802.11ah WLAN setup. The LCN demo audience will be easily motivated to discuss the advantages and disadvantages of the upcoming IEEE 802.11ah WLAN with the help of the proposed IEEE 802.11ah WLAN prototype.

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