Poster Abstract: An Open Source Approach to Field Testing of WLAN up to IEEE 802.11ad at 60 GHz Using Commodity Hardware

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***Abstract*—We present a methodology for flexible field testing supporting WLAN including the most recent IEEE 802.11ad standard operating in the 60 GHz frequency band. The system requires only minimal interaction from the user side to gather a wide range of key performance metrics such as received signal strength, communication delay, and goodput. Our implementation is based on OpenWrt and can be deployed on a wide range of commodity hardware, down to the two-digit price range, allowing large scale field tests of novel applications. As a proof-of-concept, we used the TP-LINK Talon AD7200 Wireless Routers for indoor experiments at 60 GHz. We see our Open Source implementation as a reference for a huge variety of large scale experimentation.**

I. INTRODUCTION

Wireless communication is a fundamental aspect of many applications in today's connected world – from sensor networks and the Internet of Things (IoT), to smart factories, to cooperative automated vehicles, and to smart cities. Many of these use cases build on variants of the IEEE 802.11 WLAN standard, which can operate in such diverse frequency bands as 2.4 GHz (IEEE 802.11b/g/n), 5.8 GHz (IEEE 802.11a/n/ac, 5.9 GHz (IEEE 802.11p), and – most recently – at mmWave frequencies in the 60 GHz band (IEEE 802.11ad).

The first stepping stones for in-depth investigations of such technologies in novel application domains (e.g., smart factories, smart traffic, or smart harvesting), have always been Field Operational Tests (FOTs). They are employed both for straightforward performance evaluation of designs or for parameterizing simulative or analytical models (e.g., signal propagation characteristics, medium access behavior, or receiver characteristics). In the past, many testbeds for FOTs of IEEE 802.11 technology were developed [1] which only focus on either specific communication technologies or characteristics [2], require specialized hardware like Software Defined Radios (SDRs) [3], or focus on large scale distributed network experiments [4].

Only little progress has been made towards an openly available, reusable, easy to use framework incorporating multiple different technologies and multiple different communication metrics – resulting in numerous repetitions of beginners' errors as new technologies and applications are explored. In particular, there is a gap for supporting novel communication technologies using the mmWave frequencies in the 60 GHz band like IEEE 802.11ad.

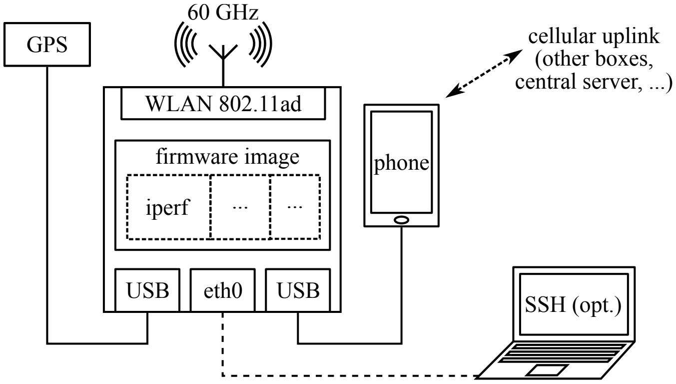

Figure 1. Overview of the measurement framework: Systems are connected via an out-of-band connection, e.g., via a tethered mobile phone. Each system allows to optionally connect a laptop to it, affording maximum flexibility in setup and mobility. Further, each system can act as receiver or transmitter, either as initiator of measurement campaigns or as a slave system.

We fill this gap with a methodology for FOTs of IEEE 802.11 applications on the 2.4 GHz, 5 GHz, and 60 GHz bands that builds on years of expertise in producing reliable, reproducible results. Our reference implementation is available as Open Source Software.[1]

The system requires only minimal interaction from the user side to gather a wide range of key performance metrics such as received signal strength, communication delay, and goodput. In addition, the reference implementation is based on OpenWrt and can be deployed on a wide range of commodity hardware, down to the two-digit price range, allowing large scale field tests of novel applications.

II. OUR MEASUREMENT FRAMEWORK

In order to perform the measurements, we orchestrated our OpenC2X prototyping platform [5], which builds upon the LEDE fork of the OpenWrt[2] framework to generate easy deployable firmware images for various hardware configurations. To support 60 GHz wireless communication on systems like TP-LINK Talon AD7200 Wireless Routers, we also build upon the Talon Tools Project.[3] In Figure 1, we outline the base architecture of our developed system:

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[1] http://www.ccs-labs.org/software/fot-box/
[2] https://openwrt.org/
[3] https://seemoo.de/talon-tools/

- Sender and receiver system set up a control connection via an ssh tunnel, e.g., by using a tethered mobile phone and a server reachable from the Internet, thus, keeping the link strictly off the wireless spectrum under study.
- During measurements, each device logs position data from an off-the-shelf GPS receiver.
- At the receiver an interactive shell-script can be invoked, guiding the user through a measurement campaign and connecting via ssh to the transmitter to start and stop all required applications without the need of user intervention.
- All data is automatically logged at both receiver and transmitter in CSV format, allowing human inspection and streaming. Our FOT-Box implementation also includes scripts that allow live inspection for judgement calls on, e.g., whether additional measurements are required.

A. *Performance Evaluation Metrics*

We developed our measurement framework with a focus on extensibility, but with three main network metrics for evaluating the quality of wireless communications in mind.

1) Received Signal Strength and Packet Delivery Ratio: To evaluate the signal strength at a certain distance, we periodically broadcast frames and take advantage of the information included with the radiotap header of each frame received from the wireless card, or (for mmWave communications) on information directly provided by the firmware of the card [6]. At the receiver we record this data together with the current location. In Figure 2 we show the Signal to Noise Ratio (SNR) for IEEE 802.11ad communications in an example scenario (each box plot corresponds to an antenna sector). From this data, calculating the Packet Delivery Ratio (PDR) for measuring higher-layer performance is straightforward.

2) Communication Latency and Goodput: Moving from single-frame transmissions to streaming data, we perform measurements in a saturated channel configuration of both TCP and UDP traffic – that is, observing retry mechanisms on the Medium Access Control (MAC) and/or transport layers, network buffers, and IEEE 802.11 QoS (e.g., transmit opportunity) settings. For this, we employ the tools Sockperf[4] and iperf, which can measure latency and goodput, respectively.

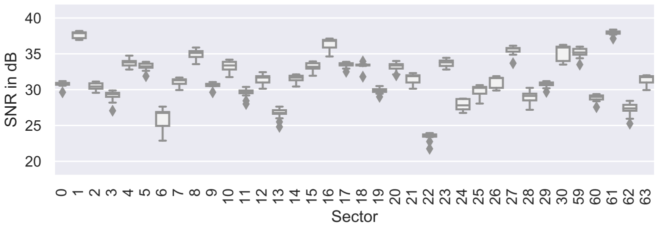

Figure 2. Signal quality (SNR) of 60 GHz communications in an example scenario for different defined antenna configurations (referred to, by the hardware, as *sectors* 0-30 and 59-63; please note that there is no direct correspondence of these configurations to antenna angles, see [6]).

B. *Measurement Types*

We are interested in the performance of wireless communication for both static scenarios (with various, but static distances between sender and receiver), and mobile scenarios (incorporating, e.g., driving maneuvers of sender and receiver). For this, our system supports two operation modes:

Static: Sender and Receiver have a static position and do not move during the recording of the performance metrics. Upon finishing the measurement, the receiving node moves to the next position, then it starts another measurement. One use case for this type could be along a street with a measurement point every few meters; or around a circle where the transmitter (or receiver) stays in the middle and every few degrees a measurement point is taken – allowing, e.g., the recording of antenna patterns of off-the-shelf hardware.

Dynamic: During the measurement the position of sender and receiver can change; we thus record only metrics concerning individual frames. This allows us to determine the impact of, e.g., obstacles during driving maneuvers on the received signal strength. Evaluation of other metrics in a dynamic measurement when nodes change their position is challenging, since the rate selection/beam alignment algorithms of the wireless hardware also takes time to determine the best configuration for transmission which would falsify our measurement results.

III. CONCLUSION

We presented our novel Open Source measurement framework for IEEE 802.11-based communications in various frequency bands, most importantly now supporting mmWave communication in the 60 GHz band for IEEE 802.11ad. Based on metrics covering the received signal strength, packet delivery ratio, communication delay, and the goodput, our system allows to precisely characterize the IEEE 802.11ad performance in various scenarios. Future work encompasses the integration of our proposed system into a wireless network simulator in order to generate trace-driven wireless channel models.

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[4] https://github.com/Mellanox/sockperf