Demo: Enabling UWB Sensing Array on COTS Wi-Fi Platform

Zhiping Jiang, Xu Wang, Chen He, Rui Li
School of Computer Science and Technology, Xidian University, Xi'an, China
{*zpj, rli*}@xidian.edu.cn, xuwangx@hotmail.com, chenhe.xd@outlook.com

Abstract

Radio Frequency (RF) sensing based on Commercial Off-The-Shelf (COTS) Wi-Fi devices is recently a hot research topic. However, the pursuit of higher sensing accuracy is severely hampered by the limited spectrum and insufficient number of antennas. In this paper, we release PicoScenes, a sophisticated NIC control and CSI measurement tool that overcomes the above limitations. PicoScenes comprises a three-layered architecture, *i.e.* PicoScenes Driver, Platform and Plug-in Development Kit (PSPDK). In the bottom layer, we unlock the Ultra-wideband (UWB) access for Atheros 9300 NIC (a.k.a QCA9300), and enable the multi-NIC CSI measurement for both Intel 5300 (a.k.a IWL5300) and QCA9300. In the middle layer, PicoScenes Platform wraps all the low-level NIC controls, and provides a powerful and efficient runtime APIs for PSPDK. And in the upper layer, we develop PSPDK-based plug-ins and achieve *ms*-grade UWB spectrum sensing on a large-scale NIC array.

1 Introduction

RF-based sensing has insatiable demand for frequency and spatial diversity, *i.e.* wider spectrum and more antennas. However, on COTS Wi-Fi platform, the limited spectrum and the lack of support for antenna array have obstructed the efforts to improve the sensing accuracy.

In this paper, we release our solution to the above problems, PicoScenes, a sophisticated NIC array control and CSI measurement system. Pursuing the goal of enabling UWB array on COTS Wi-Fi platform, PicoScenes adopts a versatile three-layered architecture namely PicoScenes Driver, Platform, and PSPDK. They will be covered in detail in the following sections. The highlight of PicoScenes are as follows. First, we unlock the UWB spectrum access for QCA9300. As exemplified by Figure 1, over GHz continual spectrum is now accessible by the low-cost COTS Wi-Fi devices. Second, we unify the CSI measurement of QCA9300 and IWL5300 in the driver level, and enrich them with the same data format. Third, we propose the integrated NIC array control platform, PicoScenes. Figure 2 shows a large-scale COTS Wi-Fi devices based sensing array managed by PicoScenes. Fourth, we develop a PSPDK-based plug-in, EchoProbe, and for the first time we enable *ms*-grade UWB spectrum sensing using COTS Wi-Fi Devices. At last, we will release PicoScenes system soon on our website [4], including the supplementary MATLAB Toolbox and documentation.

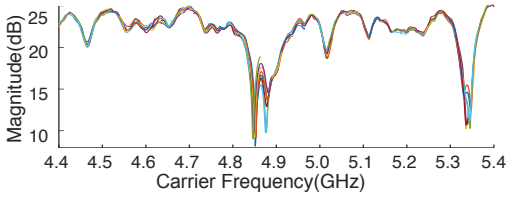

Figure 1. GHz spectrum accessible by Wi-Fi devices

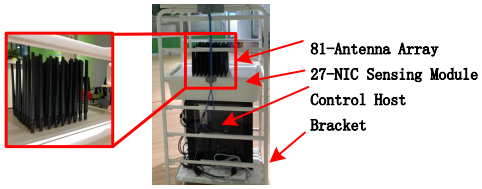

Figure 2. 81-antenna array controlled by PicoScenes

2 PicoScenes Driver

Due to the page limit, in this section, we only cover several key features of PicoScenes Driver.

UWB Access Unlocked on QCA9300: To support 2.4/5GHz dual-band, Wi-Fi NIC hardware can virtually access much wider spectrum beyond the standard channelization. For example, QCA9300's carrier frequency synthesizer (f_c synthesizer) supports over GHz spectrum in both 2.4G/5GHz bands[1]. However, these spectrum is inaccessible until we take the full control of f_c synthesizer. IWL5300 adopts the *full*-MAC design, which means its driver module only handles the high-level things, and has few control over the hardware. On the contrary, QCA9300 adopts the *soft*-MAC architect, that the driver module has the full control over almost every aspect of the hardware. After thorough exploration, we successfully unlock the UWB spectrum access for QCA9300 by taking the full control to its cf synthesizer.

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Table 1. The UWB Spectrum Supported by QCA9300

	2.4GHz Band	5GHz Band
Spectrum Range(GHz)	2.2-3.05	4.4-6.1
Min. Resolution(Hz)	250	1000

Table 1 summarizes the spectrum supported by QCA9300. Beside the total spectrum 2.5GHz , we see, in 5GHz band, the continually available spectrum is up to the remarkable 1.7GHz wide, which is 8.5x wider than the 5.5-5.7GHz continual spectrum available in standard channels.

Unified Support for QCA9300 and IWL5300: both NICs have unique features for CSI measurement that are irreplaceable by the other. However, they have for long time been kernel non-compatible, one with v4.1.10 and the other with v4.2. The deprecated kernels and the tricky installation steps have the researchers suffered a lot. We solve this issue once and always. We unify and port the CSI data collection routine of each model into the same upstream kernel v4.15, which is, to the date of publication, the official kernel version adopted by Ubuntu 18.04 LTS. Besides the code migration, the installation gets significantly simplified. Adopting the DKMS technology[2], we can release PicoScenes Driver in pre-built binary form, which is well-packaged in one single .deb file. Users can *install the driver by just double click*.

Enriched Measurement Data Collection: According to the past experience, the HW parameters of both Tx/Rx ends are very helpful to CSI data analysis. However, the off-line collection and alignment are labor intensive and sometimes challenging. We eliminate this complication by adopting an enriched CSI measurement log format, Rx Status (RxS), as shown in Figure 3. In this data format, *Rx ExtraInfo* encapsulates the Rx-end parameters. If the packet is injected by a PicoScenes-controlled NIC, Tx-end parameters will be fabricated into the packet as the *Tx ExtraInfo* part. In this way, *the HW parameters of both ends are collected in a single Rx*.

Multi-NIC Support: The existing CSI data collection routines[3, 5] only support one Wi-Fi NIC per machine. It forbids the NIC array measurement or timing-sensitive measurement. We remove this limitation by refactoring the code of RxS collection into a per-NIC mission. The RxS data of each NIC is then exposed via the individual *debugfs* nodes. To support large-scale NIC array, we carefully tune the timing of kernel threads and avoid the potential I/O congestion.

3 PicoScenes Platform

Compared to the accompanied user-space programs of the existing system, PicoScenes goes much beyond a simple CSI data logger. Embracing the versatility of the mission-specific measurement tasks, PicoScenes adopts "Platform + Plug-ins" architecture, rather than one single monolithic APP. Guided by this principle, PicoScenes Platform, provides a bunch of clean yet powerful APIs, such as fabricating and injecting HT-format packets, receiving RxS data from NIC array, manipulating NIC Tx/Rx parameters, on-line CSI data processing, and even UDP-based RxS data streaming to support CSI live plot. High performance is the other concern. Written in C++17 and built upon asynchronous I/O and multithreading technologies, PicoScenes Platform achieves 1.5K/4K Pkts/sec Tx/Rx rate on a dual-core 2.4GHz laptop.

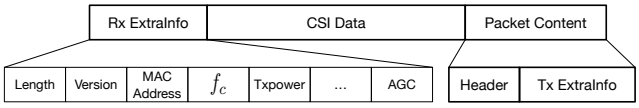

Figure 3. RxS Packet Structure

4 PicoScenes Plug-In Subsystem (PSPDK)

The APIs provided by PicoScenes are wrapped and further exposed in the pre-defined plug-in library form. We call it PicoScenes Plug-in Development Kit (PSPDK). With PSPDK, the development of the mission specific CSI measurement logic is significantly simplified. To fully demonstrate the capability of PSPDK, we release EchoProbe, a PSPDK plug-in designed to perform round-trip CSI measurement for UWB spectrum. Two Wi-Fi NICs, named *initiator* and *responder*, are required to perform UWB spectrum CSI measurement. By injecting (from initiator) and replying (from responder) EchoProbe Request packet in 802.11n HT format, CSI is measured at both ends with merely *ms* level delay. Besides the basic round-trip measurement, the initiator orchestrates the f_c swiping and protocol control. Thanks to PSPDK, the core logic of *initiator* and *responder* are coded in just 90 and 40 lines, respectively.

5 Opensource & License

The PicoScenes system is overall an open-sourced project except PicoScenes Platform. PicoScenes Driver inherits the upstream licenses and is already opensourced. To encourage the community to develop, to share and to opensource their own mission-specific PSPDK plug-ins, we license PSPDK with GPLv3, which means all of the PSPDK-based plug-ins and their derived variants, such as EchoProbe, should be opensourced. We believe this license strategy will promote and benefit the whole community.

6 Conclusions

In this paper, we release PicoScenes, a powerful CSI measurement system that overcomes several critical difficulties that obstruct the RF-based smart sensing on COTS platform for long time. It features *ms*-grade round-trip CSI measurement for UWB spectrum, multi-NIC CSI data collection and the unified data format for both IWL5300 and QCA9300 NICs. Besides the above features, the open-sourced plug-in interface (PSPDK) significant ease the pain of implementing more specific CSI measurement protocol. We hope the whole community could be benefited from PicoScenes and the future PSPDK contributors.

7 Acknowledgments

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8 References

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Setup of the Demo

Hardware Used

Two or three our customized laptops.

Space Needed

An area with six square meters at least.

Special Equipments

No need for special equipments.