Demo: WiFi-Assisted 60 GHz Wireless Networks

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ABSTRACT

Despite years of innovative research and development, multi-Gbps 60 GHz wireless networks are still not mainstream. The unfavorable propagation characteristics due to short wavelength and high directionality, makes the 60 GHz links highly vulnerable to blockage and mobility. However, the advent of multi-band chipsets opens the possibility of leveraging the more robust WiFi technology to assist 60 GHz in order to provide seamless, Gbps connectivity. In this demonstration, we will present *MUST*, an 802.11-compliant real-time system that provides seamless, high-speed connectivity over multi-band 60 GHz and WiFi devices. *MUST* has two key design components: (1) a WiFi-assisted 60 GHz link adaptation algorithm, which can instantaneously predict the best beam and PHY rate setting, with zero probing overhead at 60 GHz; and (2) a proactive blockage detection and switching algorithm which can re-direct ongoing user traffic to the robust interface within sub-10 ms latency. We have implemented *MUST* on off-the-shelf devices where our experiments show high throughput gain and almost 2 orders of magnitude cross-band switching latency improvement over state-of-the-art solutions.

CCS CONCEPTS

• **Networks** → **Wireless access networks**; **Network protocol design**;

KEYWORDS

60 GHz; Millimeter-Wave; IEEE 802.11ad; Session Transfer

1 INTRODUCTION

The multi-GHz unlicensed spectrum at the 60 GHz millimeter-wave frequency band, promises to shift today's WiFi-experience from "Wireless" to Gbps "Wire-like". With 14 GHz of free spectrum [1], 60 GHz offers foundation for next-generation bandwidth-intensive applications, such as uncompressed video streaming, snap wireless file synchronization, wireless virtual and augmented reality, wireless data centers, and Gbps Internet access. Multiple standardization efforts such as IEEE 802.11ad [9], 802.15.3c [5], ECMA [7] and millimeter-wave products [12] are tailored to support such applications, and promise upto 7 Gbps of wireless bit-rate. These advances and research demonstrations [8, 16, 19] have led millimeter-wave technology to be recommended as a key component in 5G multi-Gbps cellular networks [1–3].

However, the short wavelength (5 mm at 60 GHz) and weak reflection characteristics (compared to LTE/WiFi signals) render 60 GHz links highly vulnerable to channel propagation loss [13, 18]. In the same environment, a 60 GHz link suffers from around 1000× higher signal strength loss compared to typical LTE/WiFi [15]. Millimeter-wave devices overcome such challenge by focusing RF energy towards narrow spatial direction through beamforming using phased-array antennas. Maintaining beams from access point/base station toward mobile users is a challenging task and 60 GHz links formed via such narrow beams get highly affected during mobility and human blockage [6, 11, 15, 16].

Fortunately, the advent of multi-band WiFi chipsets [17] opens the possibility of leveraging the more robust WiFi interface in those scenarios where 60 GHz fundamentally performs poorly, to enable robust connectivity. Specifically, WiFi's omni-directional view of the wireless channel could be leveraged to design highly-adaptive 60 GHz beam and PHY rate selection. In the scenarios where 60 GHz link cannot be established due to obstacles, WiFi could provide admittedly lower speeds, but still a very robust communication anchor.

In this demonstration, we will present *MUST* [14], an 802.11-compliant real-time system which provides high-speed, robust connectivity over 60 GHz and WiFi multi-band devices, in dynamic indoor environments. *MUST* achieves its objective by introducing *two* key design components: (1) *Fast link adaptation:* A WiFi-assisted 60 GHz link adaptation module that can instantaneously predict the best 60 GHz beam and PHY rate setting, with zero 60 GHz probing, under blockage and mobility; (2) *Seamless switching:* A low-latency (sub-10 ms), proactive switching algorithm to reroute traffic from highly fragile 60 GHz links to WiFi, without breaking the existing connection. *MUST* design is built upon *two* key observations: (1) Human mobility and blockage affect the dominating path of the 60 GHz channel and thus best beam, at much slower pace (order of 100s of ms). While a small scale variation can still affect channel quality of the best beam, it does not necessarily change the entire best beam direction in a practical system. Thus, instead of relying on the existing method of link adaptation that itself can take hundreds of ms to converge, *MUST* use out-of-band information with appropriate modeling that provides the hint for the 60 GHz channel's most dominating path and best link settings. (2) When LOS is blocked, 60 GHz provides highly dynamic, rampant zero throughput connection that eventually degrades upper layer performance. In order to achieve smooth real-time response, it is far better to proactively move to WiFi interface and survive blockage. We have implemented entire *MUST* design in an off-the-shelf IEEE 802.11ac/ad multi-band AP platform (Figure 1) without any modifications to the end-user device or additional standards support. Our experiments show that *MUST* can accurately approximate the best performance link settings under various channel dynamics in enterprise environment. Even after including all out-of-band probing and interface switching related overheads, it stays within 10% of the optimum and achieves 25-60%

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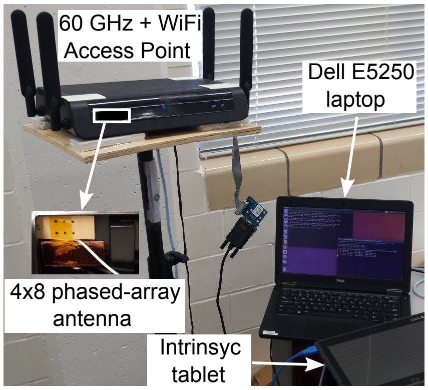

Figure 1: Off-the-shelf 60 GHz and WiFi multi-band platform.

throughput gain over state-of-the-art solutions. While proactively switching to WiFi can occasionally incur performance loss (less than 6% on average), *MUST* improves the switching latency by almost 2 orders of magnitude.

2 OVERVIEW

MUST is an 802.11-compliant system that provides seamless, high-speed 60 GHz connectivity in dynamic indoor wireless networks. The key idea is to leverage the existing robust WiFi technology to assist 60 GHz links. Practical challenges emerge when designing WiFi-assisted 60 GHz communication for *three* key reasons. *First*, while omni-directional WiFi Channel State Information (CSI) could provide a hint to the most dominant propagation path of wireless channel, it is very-coarse grained estimation, and often leads to erroneous beam and PHY rate selection. *MUST* builds a dominating LOS path tracking model [14] together with the non-uniformity of the practical phased-array antennas (Figure 2) to adapt to the best 60 GHz beam and PHY rate. *Second*, simultaneously transmitting data over highly heterogeneous-speed (*i.e.* 60 GHz and WiFi) interfaces can degrade applications' performance running over TCP by as much as 5×. This is due to out-of-order TCP sequences and congestion control over heteregeneous links [10, 14]. *MUST* thus adopts a fast switching from 60 GHz to WiFi during LOS blockage. *Finally*, designing seamless 60 GHz-WiFi interface switching, which meets the sub-10 ms latency requirements of many real-time applications, remains an open problem. Existing off-the-shelf multi-band devices adopt a reactive interface switching approach, which requires multiple seconds to identify and switch to the best interface. *MUST* employs a proactive solution for fast switching between wireless interfaces [14].

We have implemented *MUST* on the 60 GHz and WiFi AP (Figure 1) without any modification to the end-user devices. Our implementation spreads across our AP's kernel and firmware, as shown in Figure 3 and the software architecture follows open source OpenWrt [4] design. We modified kernel and firmware of the AP to periodically collect link statistics from both the 60 GHz and WiFi radios and extract them to a large DDR buffer. This statistics drive the 60 GHz prediction module to adapt the beam and PHY rates. Further, we adopt and modify the existing IEEE 802.11ad FST design [9] and appropriately modified the Linux's bonding driver to incorporate the practical interface switching. We refer interested readers to [14] for more detailed discussion on the design and implementation of *MUST*.

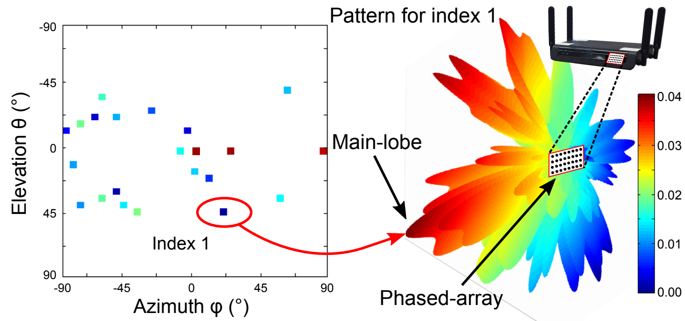

Figure 2: (a) Phased-array beam directions. (b) Measured 3D radiation pattern of beam index 1.

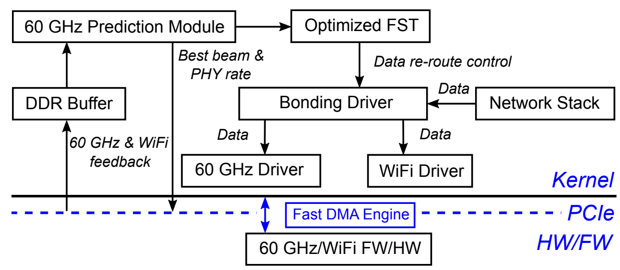

Figure 3: *MUST* system architecture. Refer [14].

3 DEMONSTRATION

In this demonstration, we will show real-time *MUST* system and its efficacy to enable robust, Gbps 60 GHz connectivity in dynamic indoor environment. In this system, we will demonstrate real-time 60 GHz beam-searching/steering with off-the-shelf phased-array devices, visualize transmit beam patterns, fast switching between 60 GHz and WiFi interfaces and run real-time ultra-HD stream under challenging and dynamic indoor environments. We will bring off-the-shelf multi-band 60 GHz and WiFi access points, laptops and tablets and our own visualization devices for the demonstration. However, we will need around 2m×2m space with a desk to place the equipments and power outlet for the devices. Our demonstration does not require any Internet access and the whole setup process should take less than half an hour.

4 CONCLUSION

By leveraging existing robust WiFi technology *MUST* enables high-performance, robust 60 GHz wireless networks. *MUST* is designed and implemented using standard, off-the-shelf hardware that provides seamless, high-speed connectivity in highly dynamic 60 GHz indoor environments. *MUST* introduces a WiFi-assisted 60 GHz link adaptation module that can instantaneously predict the best 60 GHz beam and PHY rate setting. It further designs a proactive switching algorithm to achieve sub-10 ms switch to WiFi, allowing latency-sensitive traffic to run seamlessly over existing network stack. This demonstration will showcase *MUST* in the *MobiCom'17* conference site, using off-the-shelf 60 GHz access points with unmodified commodity user devices. We believe this will trigger substantial interests and a strong push towards enabling mainstream Gbps 60 GHz wireless networks.

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