

# mm-View: Obtaining Real-Time Lower Layer Information of Commercial Off-The-Shelf 60 GHz Hardware

Adrian Loch\*, Guillermo Bielsa\*<sup>†</sup>, Roberto Santos\*<sup>†</sup>, and Joerg Widmer\*

\*IMDEA Networks Institute, Madrid, Spain

<sup>†</sup>Universidad Carlos III de Madrid, Spain

Email: {firstname.lastname}@imdea.org

**Abstract**—The lower layer characteristics of 60 GHz wireless networks impact the entire protocol stack. This includes effects such as sudden link failure due to blockage, high packet loss due to deafness, or suboptimal transmit rates due to antenna misalignment. To understand the resulting behaviors at the upper layers, it is key to have access to lower layer information. At the time of writing, 60 GHz experimentation hardware is either limited in terms of bandwidth, real-time capability, or does not support a full stack. In contrast, commercial off-the-shelf (COTS) hardware covers all of the above features but is a black box regarding the lower layers. Our demo exploits hidden monitoring capabilities of a certain COTS device which has become popular in the 60 GHz research community. The demo allows conference attendees to interact with 60 GHz links and observe how this impacts lower layer parameters. Moreover, the demo shows how such interactions relate to the performance at the upper layers.

## 1. Introduction

Obtaining lower layer information in millimeter-wave networks is crucial to understand effects at the upper layers. In contrast to wireless networks operating at lower frequencies, the need for directional communication and the high attenuation in the millimeter-wave band can have a strong impact at the upper layers. However, relating the effects at the upper layers to events at the lower layers is highly challenging in current network deployments. Unfortunately, the hardware which is currently available either does not support a full protocol stack [1], has limited bandwidth [2], or is a commercial off-the-shelf (COTS) device and thus a black box regarding lower layer information [3]. Despite this black box design, COTS devices operating in the 60 GHz band are highly interesting since most of them implement the 802.11ad standard [4] and are thus able to run a full networking stack. Moreover, such devices use full bandwidth channels as defined in the standard, and are highly flexible in terms of beam steering due to the use of phased antenna arrays. Hence, the key to understand the relation of upper and lower layers in 60 GHz is obtaining lower layer information of COTS devices.

In this extended abstract, we present the mm-View demonstrator, which obtains lower layer information in real

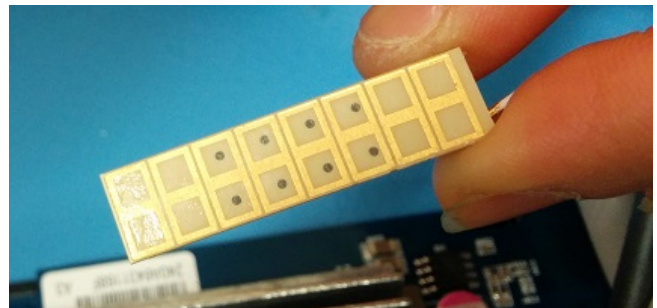


Figure 1. Antenna used by our 60 GHz chipset

time from a COTS 60 GHz device popular among researchers. In particular, mm-View operates on devices based on the Wilocity Marlon chip (c.f. Figure 1), such as the Dell D5000 docking station system [5], [6], [7]. Existing work using this platform is limited to measuring the upper-layer throughput, and the data rate displayed on the driver Graphical User Interface (GUI). In contrast, mm-View displays up-to-date information from across the entire protocol stack. Moreover, mm-View also allows conference attendees to control the type of traffic that shall be transmitted in terms of, e.g., traffic load, and traffic burstiness. Attendees can also physically interact with the 60 GHz links by causing blockage or device movement, and directly observe the resulting impact on the demo display. This includes changes ranging from the antenna alignment at the physical layer, to TCP details at the transport layer. In other words, mm-View allows attendees to relate events at the lower layers with effects at the upper layers. To this end, we find hidden monitoring capabilities in the Marlon chipset [8], use tools such as iperf to generate traffic, and build an intuitive demo GUI to visualize information (As seen in Figure 2).

In the remainder of this extended abstract, we first present the design of our demo in Section 2. After that, we explain the detailed capabilities of mm-View in Section 3. Then we provide details on the demo setup in Section 4, including equipment and space requirements. Finally, we give some concluding remarks in Section 5.

## 2. mm-View Design

We design mm-View to operate on a Dell Latitude E7440 laptop, which uses a Marlon card to establish a 60 GHz link



Figure 2. mm-View GUI

with a Dell D5000 docking station. Since the D5000 cannot act as the endpoint of a connection at the transport layer, the D5000 is further connected via Ethernet to a server. The mm-Wave GUI runs on the E7440 laptop to directly access the lower layer information of the Marlon card.

## 2.1. Lower layers

mm-View accesses parameters at the physical and Medium Access Control (MAC) layers using the so-called “Wilocity Monitor”. The monitor is included in the Marlon driver and runs as a Windows service. It is evidently not designed for use by the final customer but for debugging purposes. It remains unclear why such a tool is included in the official driver provided on the Dell website for the Marlon card. Essentially, the monitor periodically logs any value in the address range  $0x880000$  to  $0x931FFC$  of the chip memory. Each address contains 32 bits of raw information. The specific addresses—and bits within each address—that the tool shall monitor are specified in a separate configuration file. Similarly, a second configuration file allows setting the periodicity at which the content of the addresses shall be logged, and whether the monitor shall perform a memory dump when restarting the service.

The main challenge when using the monitor stems from the fact that it does not specify which information is stored in which address. In other words, the monitor provides access to a vast amount of information but does not give any hints regarding its meaning. Fortunately, one of the monitor configuration files contains a few preset addresses which again are most likely a remainder of debugging activities. This includes information such as Cyclic Redundancy Check (CRC) counters, number of detected packets, and Automatic Gain Control (AGC) values. Additionally, we infer the memory location of both the current Modulation and Coding Scheme (MCS) and the beam pattern indexes. mm-View collects all of this information from the monitor, processes it if needed, and displays it.

## 2.2. Upper layers

At the upper layers, mm-View generates TCP and UDP traffic with different parameters. To this end, we use tools such as iperf and Ostinato [9]. The former allows attendees to experiment with TCP dynamics and traffic load. The latter provides control on traffic burstiness, which in turn affects frame aggregation. Further, mm-View displays upper layer information such as throughput and latency. Since values are collected with sub-second resolution, mm-View shows them on a time-line such that attendees can follow variations.

## 3. mm-View Capabilities

In the following, we describe how conference attendees can interact with the mm-View demo, and which effects they can observe. The list is not exhaustive—attendees can easily find more creative ways to explore the relation of upper and lower layers in 60 GHz.

### 3.1. Directional communication

We first focus on issues that are related to the directional nature of communication in the 60 GHz band, such as blockage, beampatterns, mobility, and deafness.

**3.1.1. Blockage.** A simple mm-View experiment is to start a high speed data transfer on the 60 GHz link, and walk through the link. The GUI displays the transport layer throughput, as well as the MCS and the beampatterns in use. When attendees block the link, the throughput quickly drops from hundreds of megabits per second to zero. Moreover, the MCS becomes unstable as the D5000 and the E7440 laptop try to recover the link. To this end, they also attempt using different beampatterns to improve the Signal-to-Noise Ratio (SNR).

**3.1.2. Beampatterns.** The mm-View GUI displays the beampattern index in real-time. Hence, conference attendees can observe how the beampatterns change as they move the D5000. If they move the device such that it remains aligned to the E7440, the beampatterns do not change. If they move it sideways, the devices update the beampatterns in use as the SNR drops.

**3.1.3. Device rotation.** Attendees can also rotate the D5000 to observe how the movement of typical hand-held devices such as mobile phones would impact the performance of a 60 GHz link. Since the D5000 covers a  $180^\circ$  area, this gives an intuition on how a mobile phone with a 60 GHz antenna array on only one of its sides would perform.

**3.1.4. Deafness.** If space constraints at the demo location permit (c.f. Section 4), we can install two mm-View links operating simultaneously. This would allow conference attendees to explore the impact of deafness. In particular, the beampatterns of the D5000 are known to have low gain at an angle of about  $30^\circ$  [6]. Hence, placing a transmitter at roughly that angle increases collisions due to deafness significantly. As a result, mm-View shows lower throughput and missing TCP acknowledgments.

## 3.2. High bandwidth

Next, we describe issues that stem from the very high bandwidth available in the 60 GHz band. This includes the impact on frame aggregation and TCP dynamics.

**3.2.1. Traffic burstiness.** The mm-View GUI allows attendees to switch between generating data packets at regular intervals, or generating bursts of traffic. The latter results in higher frame aggregation at the lower layers, which in turn reduces medium usage. The basic intuition behind this is that, the more frames can be aggregated, the less often the device has to contend for the medium. In case of deafness among two mm-View links, increasing frame aggregation directly translates into fewer collisions and thus better performance for both links.

**3.2.2. Packet error rate.** The Wilocity monitor provides access to the so-called INA counter, which reflects the number of packets that the physical layer correctly detects. Moreover, we also have access to the number of packets that pass the CRC check. The mm-View GUI displays the difference of both counters, which gives an intuition of the packet error rate. This does not take into account packets which are not received at all due to, for instance, antenna misalignment. However, it allows conference attendees to observe how the packet error rate increases with distance, as long as the D5000 chooses the same MCS.

**3.2.3. TCP dynamics.** Finally, mm-View also provides insights regarding the impact of lower layer effects on TCP dynamics. If the endpoints of the connection are the D5000 and the E7440 laptop, the Round-Trip Time (RTT) is very small, thus allowing TCP to recover quickly after, for instance, a blockage. However, if we place one end of the connection at a remote server, the high RTT hinders TCP from adapting properly to the extreme throughput variations of the 60 GHz link. The mm-View GUI shows this in terms of TCP throughput and measured RTT.

## 4. Demo Setup

The demo setup is relatively flexible in terms of space constraints and hardware requirements. The equipment needed for one mm-View link is one D5000 docking station, one Dell E7440 laptop, and one laptop that acts as the second endpoint of the link. If space allows, we could easily deploy a second 60 GHz link to study the impact of deafness (c.f. Section 3.1.4). This would just require two of each of the aforementioned devices. If a projector is available on-site, the demo can be further enhanced by showing the mm-View GUI on a screen next to the 60 GHz links. While not strictly needed, this would allow conference attendees to directly observe how interacting with the links impacts performance.

The space required for the demo is flexible. If possible, a  $4m \times 2m$  area with two tables would be best, since this allows attendees to easily walk through the links and interact

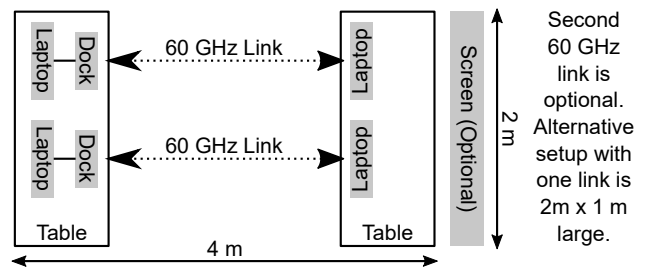


Figure 3. Scalable demo setup

with the hardware. Figure 3 shows how the setup could be. However, we can easily scale down the demo if needed. The setup time is roughly half an hour. Regarding additional facilities, the demo requires power, and, if possible, a wired Internet connection to connect to a remote TCP server (c.f. Section 3.2.3).

## 5. Conclusions

We present the mm-View demo, which exploits hidden monitoring capabilities of the Wilocity Marlon 60 GHz chip to gain access to lower layer information of COTS devices. This enables mm-View to relate events at the lower layers with effects at the upper layers.

## References

- [1] National Instruments, “mmWave Transceiver System,” <http://www.ni.com/sdr/mmwave/>, [Accessed June 3, 2016].
- [2] J. Arnold, L. Simic, M. Petrova, and P. Mähönen, “Demo: Spectrum-Agile mm-Wave Packet Radio Implementation on USRPs,” in *Proc. of SRIF’15*, 2015.
- [3] TP-Link, “Talon AD7200 Multi-Band Router,” <http://www.tp-link.com/en/products/details/AD7200.html>, [Accessed June 3, 2016].
- [4] IEEE, “Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications Amendment 3: Enhancements for Very High Throughput in the 60 GHz Band,” *IEEE Std 802.11ad-2012*, pp. 1–628, Dec 2012.
- [5] Y. Zhu, Z. Zhang, Z. Marzi, C. Nelson, U. Madhow, B. Y. Zhao, and H. Zheng, “Demystifying 60GHz Outdoor Picocells,” in *ACM MobiCom’14*, 2014.
- [6] T. Nitsche, G. Bielsa, I. Tejado, A. Loch, and J. Widmer, “Boon and Bane of 60 GHz Networks: Practical Insights into Beamforming, Interference, and Frame Level Operation,” in *Proc. of CoNEXT’15*, 2015.
- [7] S. K. Saha, V. V. Vira, A. Garg, and D. Koutsonikolas, “60 GHz Multi-Gigabit Indoor WLANs: Dream or Reality?” *CoRR*, vol. abs/1509.04274, 2015. [Online]. Available: <http://arxiv.org/abs/1509.04274>
- [8] A. Loch, G. Bielsa, and J. Widmer, “Practical lower layer 60 ghz measurements using commercial off-the-shelf hardware,” in *Proceedings of the Tenth ACM International Workshop on Wireless Network Testbeds, Experimental Evaluation, and Characterization*. ACM, 2016, pp. 9–16.
- [9] “Ostinato - Network Traffic Generator/Analyzer,” <http://ostinato.org/>, [Accessed July 15, 2016].