Streaming 8K Video over Millimeter Wave Networks: An Experimental Demonstrator

Hemanth Kumar Ravuri *, Jakob Struye†, Maria Torres Vega*‡, Jeroen van der Hooft*, Jeroen Famaey†, Tim Wauters*, Filip De Turck*

*Ghent University - imec, Ghent, Belgium. Email: {firstname}.{lastname}@ugent.be
†University of Antwerp - imec, Antwerp, Belgium. Email: {firstname}.{lastname}@uantwerpen.be
‡KU-Leuven, Leuven, Belgium. Email: {firstname}.{lastname}@kuleuven.be

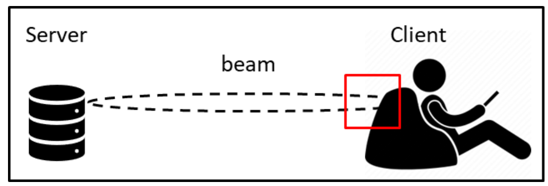
***Abstract*—Millimeter wave (mmWave) communication technology is expected to enable ultra-high speed and ultra-low latency communications owing to the availability of high-capacity bands at a frequency range of 30 GHz to 300 GHz. Despite its abundant resources, it is prone to signal attenuation due to blockage and mobility. So far, evaluations of first generation mmWave hardware are limited to lower-layer metrics. In this demonstrator, we propose to evaluate the multimedia application performance while using commercial off-the-shelf routers, using an 8K video streaming scenario. To achieve this, this paper introduces a mmWave testbed which incorporates mobility and blockage while streaming the video. In addition, it provides a detailed description of the steps involved in the deployment of experiments and analysis of the results.**

***Index Terms*—Millimeterwave networks, 8K, video streaming**

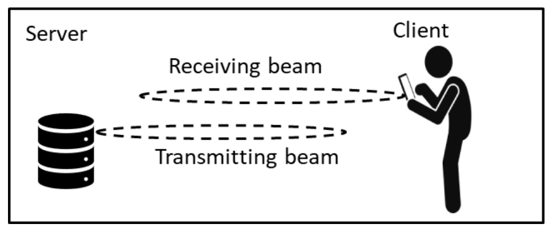
I. Introduction

Millimeter wave (mmWave) communications technology is on its way to become the cornerstone of fifth generation (5G) and sixth generation (6G) mobile communication networks for high-rate and high-reliability low-latency communications (HR2LLC) [1]. Currently, wireless transmissions operate on low-frequency bands (300 kHz to 3 GHz) with limited resources in terms of data rate, making it difficult to meet stringent bandwidth and latency requirements of next-generation application domains such as Industry 4.0, telehealth, entertainment, or immersive technologies [2].

With its abundant spectrum resources and very high bandwidth (30 GHz to 300 GHz), mmWave communications technology is expected to offer a plethora of opportunities for such applications. However, compared to existing wireless technologies, mmWave is susceptible to blockage and the signal attenuates quickly with distance. Since mmWave operates at high frequency, it has less penetration power, and therefore requires a clear line of sight (LoS) between the transmitter and receiver for optimal performance. Figure 1a presents a scenario, where a user's cushion creates a blockage between the server and client, there by blocking the LoS. Such scenarios pose challenges such as high propagation loss, leading to under-utilization of mmWave's capabilities.



(a) Blockage in mmWave.



(b) Beam misalignment in mmWave.

Fig. 1: Challenges for mmWave communication technology.

To address this issue, beamforming has been adopted as an essential technique, where energy will be focused on specific directions to ensure high signal strength where desired. Toward this end, mmWave uses highly directional antenna arrays to focus the signal into a narrow beam. Although beamforming is useful, it can be challenging in a highly mobile environment, where it must adapt quickly. Figure 1b presents a scenario in which the user from Figure 1a stands up, leading to misalignment of the transmitting and receiving beams. This requires the transmitter to quickly steer and realign its beam with the receiver's beam to establish a clear LoS. Therefore, it is important to address the challenges offered in scenarios that involve high mobility and blockage [3].

Wirelessly connected Virtual Reality (VR) with six degrees of freedom (6DoF) is an example of such a scenario, where the user walks around while interacting with an object in a scene. Here, objects in the physical environment and the bodies of other users can create a blockage. In this context, we have presented the capabilities and challenges of VR over mmWave in our earlier work [4]. Unlike the previous works, which evaluated VR over mmWave using models, simulation and experiments, we have employed commercial off-the-shelf (COTS) standard-compliant IEEE 802.11ad routers to build a

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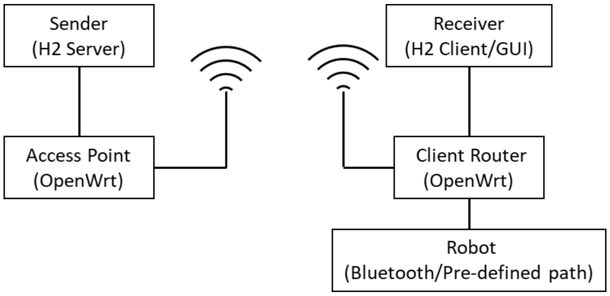

Fig. 2: Demonstrator setup.

Fig. 3: Picture with sender and receiver having LOS [4].

novel testbed for mmWave with repeatable mobility [4].

In this paper, we present a demonstrator for experimentally evaluating the capabilities and challenges of mmWave while running applications with high bandwidth requirements using said testbed. In this direction, we analyze the application layer performance while streaming an 8K video over mmWave-capable routers. The testbed, designed to support a real-world wireless video streaming scenario, is capable of introducing several levels of blockage and deploys the client on a robot platform for repeatable mobility. Furthermore, we present performance results for the video streaming application (throughput and modulation coding scheme (MCS)) on a real-time graphical user interface (GUI). In the remainder of the paper, we first introduce our experimental testbed, then cover the demonstration scenario, and finally present and analyze the application performance.

II. Experimental Testbed

Figure 2 presents the testbed, which is carefully designed to evaluate the performance of mmWave in a mobile environment. Firstly, the sender is a laptop hosting a Jetty webserver[1] capable of streaming 8K content using the second generation hypertext transfer protocol (HTTP/2) over the transmission control protocol (TCP), which is the most widely deployed protocol for reliably streaming videos. The sender is connected to a TP-Link Talon AD7200 mmWave router[2] which acts as an access point (AP). On the client side, a second router is placed on top of a Rover Robotics 4WD Rover Pro robot[3]. Figure 3 presents a picture of the setup with the client mounted on the robot and having a clear LOS with the sender. The sender and receiver are connected to their respective routers using a gigabit Ethernet cable. Although routers are capable of achieving throughput beyond 1 Gbps, it is limited by the cable capacity on the current testbed. The routers are connected in a master-client network using the wireless link and run a custom fork of OpenWrt[4]. This version offers complete support for this router by improving performance in terms of CPU usage. As mentioned in [4], the performance of the routers degraded while performing layer 3 routing. To address this issue and achieve 1 Gbps throughput over the wireless link, we used the *relayd package* and fixed the maximum transmission unit (MTU) along the path to 1986 bytes (the highest that the mmWave chipset supports).

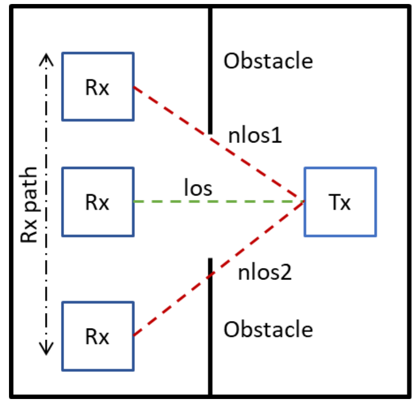

Fig. 4: Demonstration scenario.

An ADLINK Vizi-AI devkitboard[5], mounted on top of the robot, takes on the role of receiver. The receiver runs a simple Python-based client to play out the video and collect metrics such as observed throughput in real time. The streamed videos can be played on a screen connected to the receiver. We have designed a multipurpose GUI using Python and deploy Python-VLC[6] module to play out the received content. Furthermore, the client performs passive measurements in terms of throughput and MCS for the router. The GUI updates the observed values over time. Moreover, mounting the client side completely on the robot provides the opportunity to incorporate repeatable mobility patterns for a precise evaluation of the impact of mobility. The robot can be controlled using joysticks via a Bluetooth interface. However, for the sake of repeatable mobility patterns, we deploy emulated joysticks on the robot.

III. Demonstration Scenario

In the following, the demonstration is thoroughly explained:

- The demo introduces the functional blocks of the testbed illustrated in Figure 2. Furthermore, we explain the networking aspects involved in designing the testbed. Next, we briefly provide details of the underlying hardware.
- Then, we introduce the demonstration scenario as presented in Figure 4. The scenario is chosen to evaluate the opportunities and challenges in using mmWave for applications with high bandwidth requirements. In order

[1] https://www.eclipse.org/jetty/
[2] https://www.tp-link.com/us/home-networking/wifi-router/ad7200/
[3] https://roverrobotics.com/products/4wd-rover-pro

[4] https://seemoo.de/talon-tools/
[5] https://www.adlinktech.com/
[6] https://pypi.org/project/python-vlc/

to incorporate mobility, we mount the receiver (Rx) on the robot and move it along the predefined path. Furthermore, to introduce blockage, we stop the robot in three predefined positions, where there is a clear LoS (los), the edge of an obstacle blocks the LoS (nlos1) and the middle of the obstacle blocks the LoS (nlos2).

- The position of nlos1 differs from that of nlos2 due to the fact that the reception at nlos1 is constantly and considerably higher than nlos2. This is because the penetration power of the high-frequency signal varies with the thickness of the obstacle, since the thickness of the edge of the obstacle is lower than the middle.
- As part of the demo, we drive the robot between the positions los and either nlos1 or nlos2 for every 30". In parallel, the transmitter (Tx) streams an 8K video called "Historic Ghent Belgium Scenic Relaxation Boat Tour With Calm Music For Stress Relief" [7] to the receiver. To this end, the video is encoded in one quality with an average bit rate of $350\,\mathrm{Mbps}$. We have chosen one quality to observe the impact of mmWave on video streaming visibly in the form of video freezes during packet loss. Furthermore, using iPerf[8], we present the limits of the throughput achieved by the routers.
- The real-time GUI of the client (Figure 5) displays the video and plots the observed throughput and MCS over time, for the case where the robot moves between positions los and nlos1. As shown in the example, throughput remains fairly constant even at nlos1, while the MCS is reduced considerably. However, as maximum MCS corresponds to a PHY-level throughput of roughly $2.3\,\mathrm{Gbps}$, even a significant reduction in MCS will not impact actual performance, as long as the Ethernet links in the network remain the bottleneck at $1\,\mathrm{Gbps}$. The momentary reduction in throughput can be attributed to the beam misalignment, which is resolved in less than two seconds through beam forming. Since TCP is used, this drop will cause the video to freeze momentarily until all packets are received.
- Furthermore, as confirmed by the results in [4], the performance degradation is severe when moving between positions los and nlos2. MCS drops to the lowest possible values and throughput drops accordingly. Occasionally, throughput drops to zero, thereby breaking the link.
- Thus, using COTS routers, the demo highlights the impact of mobility and blockage on mmWave when streaming an 8K video. Although mmWave communications technology is capable of achieving high throughput, work needs to be done to incorporate smart strategies to maintain consistent LoS. Furthermore, more robust beam-forming strategies are needed to avoid the beam misalignment.

IV. Conclusion

In this paper, we propose a demonstration of an experimental testbed to evaluate the performance of millimeter wave communication technology while running applications with high-bandwidth requirements. To this end, the testbed incorporates commercial off-the-shelf mmWave routers to establish a wireless link between a transmitter and receiver. Furthermore, the testbed mounts the receiver on a robot to introduce repeatable mobility. As part of the demonstration, we stream an 8K video using HTTP/2 over transmission control protocol (TCP) from the transmitter while the receiver is in motion. The mobility pattern is chosen in such a way that it emulates different cases of line of sight between the transmitter and receiver. Finally, we present and analyze the results using a real-time GUI. As part of future work, we will incorporate complex mobility patterns and user datagram protocol (UDP) based streaming protocols like QUIC.

[7] https://www.youtube.com/watch?v=uoHdMVkSsMo
[8] https://iperf.fr/

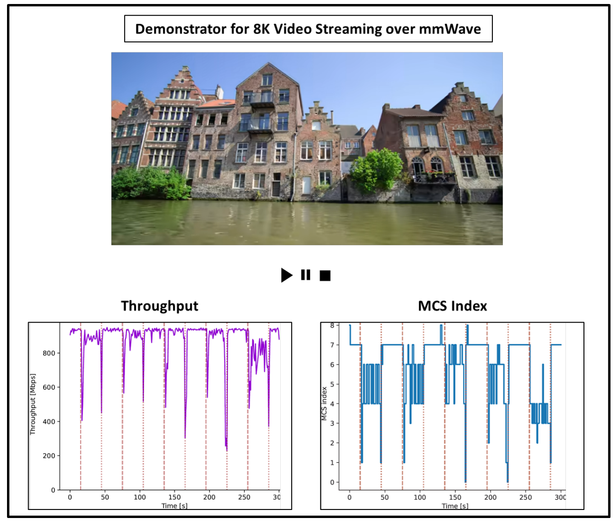

Fig. 5: Real-time GUI for the demonstrator.

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