Poster Abstract: mmWave on the Road – Field Testing IEEE 802.11ad WLAN at 60 GHz

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***Abstract*—Millimeter-Wave (mmWave) communication is gaining importance in many networking applications due to the potential of wide channel bandwidth enabling multi-gigabit throughput and low delays. In the consumer electronics field, IEEE 802.11ad is already widely available, which has been developed mainly for indoor use cases. This protocol particularly benefits from dynamic beamforming. The communication performance of these algorithms is still little explored in outdoor scenarios. We present results from field measurements of IEEE 802.11ad on the road. We started with static network scenarios and then moved to dynamic scenarios using two cars driving through the city of Berlin. As can be seen from our results, a quite stable communication is possible in static scenarios, but mobile scenarios prevent quick beam alignment and thus significantly impact the performance.**

I. Introduction

Wireless communications at Millimeter-Wave (mmWave) frequencies gained a lot of attraction in the past for providing high data rates. The IEEE 802.11ad standard supports the operation at 60 GHz using wide channel bandwidth of 2.16 GHz, enabling multi-gigabit throughput up to 7 Gbit/s. To support the communication in 60 GHz, IEEE 802.11ad introduces a set of design changes for the physical (PHY) and Medium Access Control (MAC) layers [1]. These changes aim to support Directional Multi-Gigabit (DMG) communications to overcome the propagation losses. The technique used to establish directional communication links is beamforming, which decreases the interference by focusing the energy on the receiver. Due to the communication directivity, IEEE 802.11ad defines a new hybrid channel access scheme for mmWave.

With the introduction of higher data rates for ad hoc wireless communications, the exchange of raw sensor data in the vehicular networking context becomes possible [2]. This can improve vehicle networking scenarios such as cooperative perception or platooning [3]. Recent studies of IEEE 802.11ad focus either on the performance in static networks [4], [5], mobile networks focusing on the reflection of a car roof's ground plane [6], or beamforming algorithms incorporating radar functionality in standard-compliant frames [7].

To the best of our knowledge, however, an investigation of the communication performance with respect to highly dynamic and challenging multi-path environments, e.g., in tunnels and crowded streets, is still missing. In the following, we provide first insights into the communication performance in static and mobile road traffic scenarios by taking advantage of our novel measurement toolkit FOT-Box [8].

II. Measurement Results

To assess the performance of IEEE 802.11ad wireless communications, we perform measurements for both static scenarios (with various but static distances between sender and receiver in different environments), as well as mobile scenarios (including driving maneuvers of sender and receiver in complex environments). For static scenarios, we equipped two mobile tables with TP-LINK Talon AD7200 Wireless Routers, accompanied by a notebook for control, a GPS receiver, and a 4G modem for a reliable uplink, respectively. For mobile scenarios, we moved the same setup to the roof of two cars. The hardware was powered by an inverter on the vehicles. Using this setup, we gathered data while driving in the varying city traffic and environment of central Berlin for two hours.

A. Evaluation Metrics

We focus on three main performance metrics for evaluating the quality of wireless communication using IEEE 802.11ad:

1) Signal Quality, SNR: For evaluating the signal strength at certain distances, we periodically broadcast frames. Based on the observed GPS positions, the distance is derived as provided by our measurement toolkit (FOT-Box) [8]. Information provided by the firmware of the wireless card allows us to investigate the signal quality and the number of available antenna sectors for different antenna configurations.

2) Goodput: To assess the performance of streaming data, we focus on goodput measurements using iperf in TCP mode. To exploit the maximum available link speed of IEEE 802.11ad, we operate iperf directly on the wireless routers as their Ethernet links are limited to 1 Gbit/s.

3) Communication Latency: Finally, we investigate communication latencies that are impacted by WLAN retry mechanisms as well as network buffers. We can report that the observed one-way latencies are considerable below 5 ms in most settings (not plotted due to space constraints).

B. Performance in Static Networks

As a first step, we assess the communication performance in a static setting with varying distances between sender and receiver. In Figure 1, we show the achievable goodput using iperf in TCP mode for an indoor setting (i.e., along a corridor) as well as an outdoor setting (i.e., along a street with parked cars on one side). For the indoor measurements, we achieved a relatively static goodput of around 1 Gbit/s over a distance of about 30 m. Based

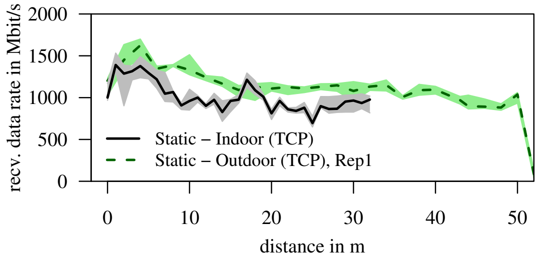

Figure 1. Goodput (Iperf TCP) of 60 GHz communications in static scenarios, both indoors and outdoors (for better readability, we only plot data for one repetition of the experiment).

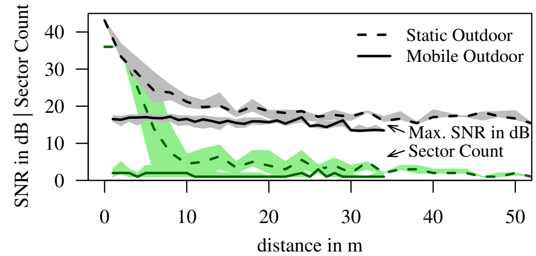

Figure 2. Received signal strength and sector count in mobile and static scenarios. In the mobile case, the distance is derived from the vehicles' GPS locations.

on the signal quality measurements (cf. Figure 2), we observed that beyond 30 m, the communication was still feasible and only limited by the length of the corridor. Moving to an outdoor scenario (thus, a more challenging multi-path environment), we observe a maximum communication distance of around 50 m over which the achievable goodput remains quite constant. We observed that by increasing the distance further (only by a few centimeters), the communication channel became completely unavailable. When repeating the measurements (with fewer nearby parked cars, thus a lower amount of multi-path effects), we discover that the communication distance has been further lowered to around 40 m. We conclude that multi-path propagation has a large impact on the communication performance: not only for the achievable goodput but also on the achievable maximum communication distance.

C. Performance in Mobile Networks

The use of mmWave communications faces more challenges in mobile scenarios, such as in our vehicular scenario. The use of beamforming is complicated during vehicle movement; the metallic surfaces of vehicles further increase the effect of multi-path signal propagation. The measurements we conducted during the mobile measurements show the impact of the high mobility experienced. As shown in Figure 2, the signal quality dropped by about 3 dB for distances greater than 10 m, which are very relevant in vehicular networking scenarios. While the effect of mobility on the signal strength is significant, the stability of the connection was more severely affected. This is indicated by the number of sectors that a signal was received on, which typically is halved, compared to the static measurements. For this reason, beyond a distance of 30 m, there are only a few recorded data points, even though the vehicles also drove at larger distances (up to 50 m). Moreover, the connection was not stable enough to conduct goodput measurements. We suspect that this loss is due to beam misalignment, as the hardware has been designed for indoor environments.

III. Conclusion and Future Work

For mmWave communications at 60 GHz, the IEEE 820.11ad standard has introduced a set of design updates to support multi-gigabit throughput. One of the important addition is DMG, which utilizes beamforming to overcome the high propagation losses. In this work, we experimentally explored IEEE 802.11ad in highly dynamic conditions for potential application in vehicular networks. Static measurements with TP-LINK Talon AD7200 Wireless Routers demonstrated reasonable antenna sector count for effective beamforming, especially in the presence of reflecting surfaces. This essentially indicated that the multi-path reflection facilitated the communication. In mobile scenarios, the sector count was very small, and the DMG eventually failed to work. This is due to the mobility of the cars resulting in a very dynamic channel, where the beam tracking failed after initial beam alignment.

Our measurement campaign underlines the challenges for mmWave in highly dynamic scenarios, where the existing PHY beamforming fails. Possible solutions to address the DMG issue include the introduction of learning-based approaches for beam alignment in mobile scenarios and using IEEE 802.11p/DSRC or Cellular V2X (C-V2X) as control channels [2] for additional information. Further, a cross-layer design between PHY/MAC and Transport Layers can help bring DMG on the road.

Acknowledgments

This work has been supported in part by the German Research Foundation (DFG) under grant no. DR 639/18-1 and DR639/23-2.

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