V-band Rain Attenuation Measurement Setup

Brecht De Beelde*, David Plets, Emmeric Tanghe, Chenglong Li, and Wout Joseph
Ghent University/IMEC, Ghent, Belgium, http://waves.intec.ugent.be

Abstract

High-frequency wireless technologies realize fixed wireless access networks as an alternative to fiber for bringing high-throughput internet connectivity to the home. In the design of wireless networks, channel models are of utmost importance for having realistic link budget calculations. This paper provides a measurement setup for obtaining rain attenuation values in the V-band, ranging from 50 to 75 GHz. By continuously measuring received power over an extended time, and linking path loss data to meteorological data, we see that rain attenuation for moderate rain intensity ranges from 0.12 dB/m at 55 GHz, to 0.22 dB/m at 70 GHz. Furthermore, other meteorological phenomena also impact measured attenuation.

1 Introduction

The high bandwidths that are available in mmWave frequency bands provide data rates that enable high-throughput applications including fixed wireless access (FWA). In FWA networks, high-speed internet access is provided via point-to-point wireless links, rather than using coaxial or fiber cable. To design wireless communication systems, channel models are necessary for antenna selection and link budget calculations. From a link budget, throughout as a function of distance to the transmitter is determined based on the gains and losses of the system. Typically, high-gain directive antennas are used for FWA applications, and therefore, gain depends on the used antenna system. Losses in the system include but are not limited to path loss, antenna mismatch, cable losses, but also environmental losses such as foliage loss and attenuation due to rain.

An outdoor path loss model for FWA at sub-6 GHz frequencies is presented in [1], whereas outdoor channel models for FWA around 30 GHz are presented in [2, 3]. Outdoor propagation measurements at 73 GHz are presented in [4, 5]. Foliage attenuation at 73 GHz is discussed in [6]. Atmospheric influence on radio propagation is investigated at various frequency bands [7, 8, 9, 10], and the International Telecommunication Union (ITU) has recommendations on attenuation due to atmospheric gasses [11] and rain [12]. However, the ITU recommendations have limitations, as outlined in [13]. The millimeter-wave propagation model (MPM) also predicts the effect of rain on a wireless link, and a model based on the size of rain drops is presented in [14].

In this paper we present a measurement setup to assess the influence of rain on a wireless link at V-band frequencies, ranging from 50 tot 75 GHz. In Section 2, we present the measurement setup and methodology. A presentation and discussion of the results follows in Section 3, and Section 4 concludes this paper.

2 Methodology

2.1 Channel sounder

We use a spectrum analyzer-based channel sounder. A R&S SMB100A signal generator generates a sine wave in frequency range 8.3 GHz to 12.5 GHz, which is upconverted to V-band frequencies 50 GHz to 75 GHz via a R&S SMZ75 frequency multiplier with multiplication factor 6 and transmitted using a directional horn antenna with a gain of 20 dBi. An identical antenna is connected to a R&S harmonic mixer type FS-Z75 that down-converts the received signal to a frequency in range 5 MHz to 2 GHz. The down-converted signal is analyzed via a R&S FSVR40 spectrum analyzer.

A manual frequency sweep is performed from 50 GHz to 75 GHz with a frequency step size 0.5 GHz. For every measurement, the span is 1 MHz, with 501 frequency points, and the resolution bandwidth is set to 50 Hz.

The measurement setup is shown in Fig. 1. The transmit (TX) antenna and signal generator are placed in the barn, and the receiving (RX) antenna and spectrum analyzer are placed indoor, behind an open window. The Line-of-Sight (LOS) distance between both antennas is 5.40 m, and the path distance which is not covered and therefore subject to rain is 5.00 m. The antennas are horizontally leveled and placed at a height of 1.37 m, and directed towards each other.

The measurements are performed in Gavere, Belgium, on November 4, 2021. Frequency sweeps are continuously performed from 14:00 until 21:00. On average, 5 samples per frequency are recorded every minute.

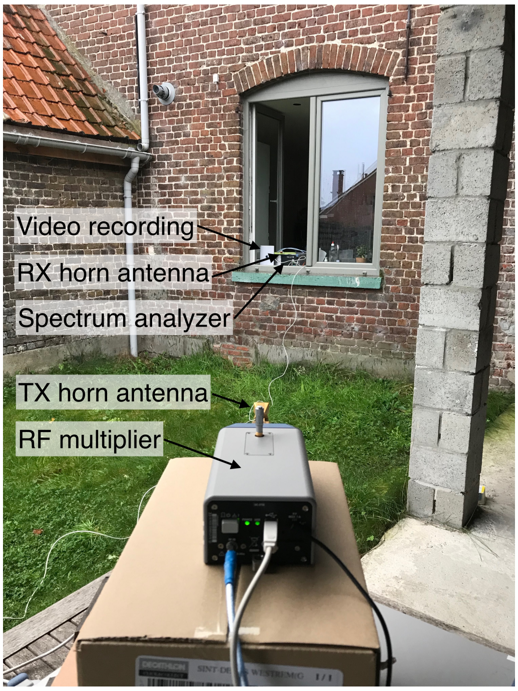


Figure 1. Measurement setup (TX view).

2.2 Weather stations

The rain intensity is monitored by capturing meteorological data from four different sources, as well as via a video recording. The channel measurement location and the location of all used weather stations are shown in Fig. 2.

The first source of meteorological data is a weather station from the Belgian Royal Meteorological Institute (RMI) [15] which is located in Melle (distance 8.3 km). The second source are two stations from the Ghent University MOCCA project [16], one located in Melle and one located Ghent. These stations have an ARG100 tipping-bucket rain gauge with 0.2 mm tips, and are capable of measuring rain intensities up to 500 mm/h. We also monitor the data from Davis Vantage Pro2 weather stations used by the Ghent University VLINDER project [17, 18]. The four stations from the VLINDER project are located in Asper (3.6 km), Zwijnaarde (9.0 km), Zevergem (6.2 km) and Melle (8.3 km). Radar data is consulted via Buienradar [19].

The different sources provide precipitation data in different formats. The RMI provides hourly data in mm/hour, the stations from the VLINDER project provide data in mm/hour every 5 minutes, whereas the stations from MOCCA provide cumulative precipitation in liter/m^2. To compare the different sources, we convert all data to cumulative precipitation in liter/m^2. The data from these sources is compared to the video recording that is made during the measurements, to get an estimate of rain intensity in Gavere.

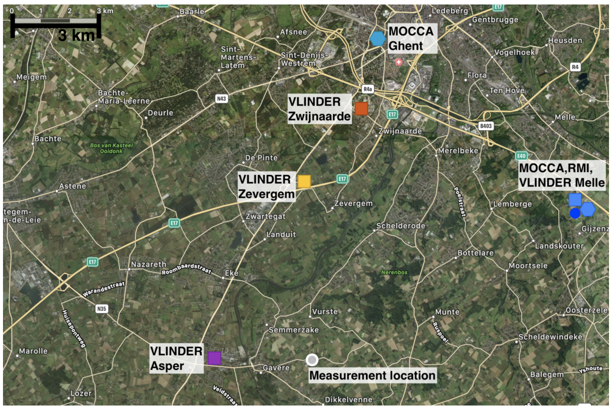


Figure 2. Location of measurement setup and weather stations.

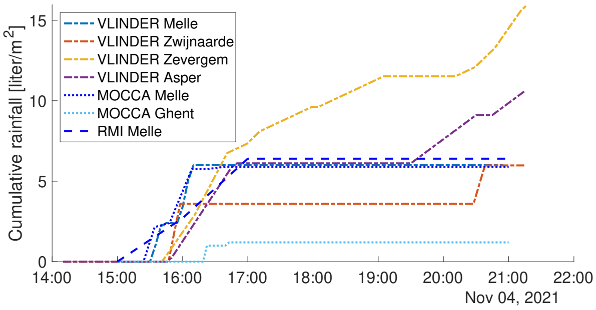


Figure 3. Meteorological data from RMI, MOCCA, VLINDER and Buienrader.

3 Results and discussion

3.1 Rain data

Figure 3 provides rainfall according to the different data sources. Analyzing the rainfall data from the different stations that are located in Melle, the measurement data from MOCCA (5.9 liter/m^2) corresponds well to data from VLINDER (6.0 liter/m^2). The measurement station from the RMI reports a slightly higher cumulative precipitation (6.4 liter/m^2). Buienradar reports rain zones at 15:25, and 15:50.

During the propagation measurements, Buienradar reports four rain zones for Gavere, moving from North to South. It first starts raining at 15:50 and stops at 16:25. There is a small rain shower at 16:50, and a larger rain zone starts at 18:45 and ends at 19:45. A last rain zone starts at 20:25 and lasts 20 minutes.

The closest VLINDER measurement station, in Asper, reports rain starting from 15:50, which corresponds to the video recording, as well as the radar data from Buienradar. As the rain zones moves from North to South, the VLINDER stations in Zwijnaarde and Zevergem report an ear-

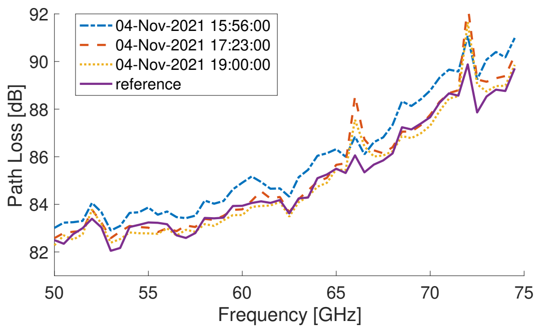


Figure 4. Measured path loss as a function of frequency for 3 different time instances.

lier start of the precipitation. According to the measurement station in Asper, the rain intensity is constant, with 0.5 mm/h, and stops after one hour. However, the video recording shows that it stopped raining after 20 minutes, and that the next rain zone starts at 18:45, which is in line with the results from Buienradar.

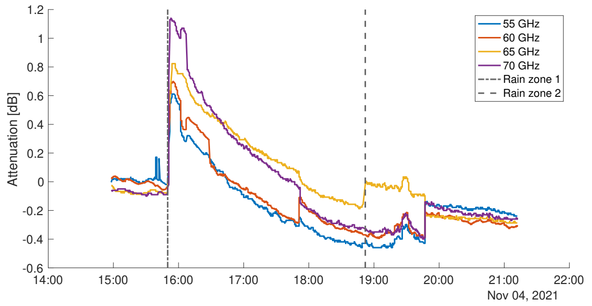
3.2 Measured path loss

PL is continuously measured for a time period of 6 hours. The first 10 measurements are taken as reference, i.e., the PL without any precipitation. The attenuation is found by subtracting the mean of the reference PL values from the measured PL. Therefore, antenna gain variations and cable losses do not influence the measured attenuation. Figure 4 presents the measured PL as a function of frequency for 3 different time instants, as well as the reference PL. Figure 5 provides the measured attenuation for four frequencies, as well as atmospheric data, as a function of time.

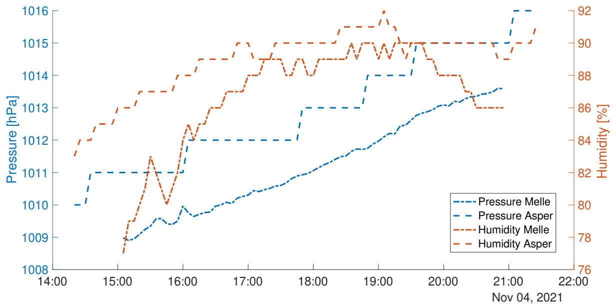
3.3 Discussion

Figure 5a shows the attenuation for different frequencies as a function of time, whereas Fig. 5b provides atmospheric measurement data from the stations in Melle and Asper, i.e., atmospheric pressure (in hPa) and humidity (in percentiles).

In Fig. 5a, we see a sudden increase in attenuation at time instant 15:50, i.e., when it first starts raining. The rain intensity is 12 mm/hour, and the attenuation for a 5 m link ranges from 0.58 dB for 55 GHz to 1.12 dB for 70 GHz, corresponding to a respective attenuation of 0.12 dB/m and 0.22 dB/m. The extrapolated attenuation for FWA links, with distances up to 100 m, ranges from 12 to 24 dB. After it stops raining, the attenuation gradually decreases. For the second rain zone, with a much smaller rain intensity, there is an attenuation increase of 0.2 dB for frequency 65 GHz, whereas at other frequencies there is only an increased attenuation at 19:30, when there was a slight rain increase.



(a) Attenuation as a function of time for frequencies 55 GHz, 60 GHz, 65 GHz, and 70 GHz



(b) Atmospheric data as a function of time: atmospheric pressure on left y-axis, and humidity on right y-axis

Figure 5. Measurement results.

From Fig. 5a, it is clear that not only the rain intensity influences attenuation, but also other (meteorological) phenomena impact propagation at V-band frequencies. As can be seen in Fig. 5b, the atmospheric pressure increases from 1010 hPa at 15:00 to 1016 hPa at 21:00, whereas the humidity increases from 83% to 91% after the first rain zone.

During the measurements, the temperature decreased from 11°C at 15:00 to 8.1°C at 21:00, which affects the circuitry of the frequency multiplier. Therefore, the decrease in attenuation after the first rain has stopped will also be related to a changing output power of the frequency multiplier which does not have automatic gain control.

The main conclusion from Fig. 5a is that we can measure attenuation for moderate rain intensity by investigation of sudden attenuation differences. A calibration of the measurement setup in a temperature-controlled environment will enable to filter temperature effects from the measurement equipment and data.

4 Conclusions and future work

In this work, a measurement setup is presented for measuring rain attenuation at V-band frequencies. A short link distance is preferred to increase the dynamic range of the measurement setup. Rain attenuation of a short-range link of only 5 m already exceeds 1 dB. Not only rain itself influences the outdoor wireless link, also changes in atmospheric characteristics impact attenuation, i.e., the wireless channel, as well as the measurement equipment.

However, for instant weather changes, e.g., when it starts raining, an increase in attenuation is observed. By mapping relative attenuation differences to weather conditions, attenuation due to rainfall is obtained.

As part of future work, this measurement setup will be calibrated and used for a long-run measurement campaign spanning multiple days, when there is a higher rain intensity, to acquire more data, and relate the data to other atmospheric parameters. Furthermore, the measurement setup will be modified for other frequency bands, by switching the RF multiplier and harmonic mixer. As an example, the same setup can be used for measuring attenuation in the D-band, by using a similar frequency multiplier and harmonic mixer.

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