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Channel Propagation Experimental Measurements and Simulations at 52 GHz

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Abstract

This paper presents a comparison of 52 GHz channel propagation measurements, conducted in an outdoor scenario, with ray-tracing simulations. The simulation and the measurements both show that long range reflections from metallic structures contribute to the received multipath components. However, the diffuse multipath components which originate from rough surfaces are captured by the channel sounder are not reproduced in the simulation. Further calibration of such tools is therefore necessary prior to their application as channel prediction tools.

1. Introduction

The last World Radio-communications Conference, WRC-15, identified several frequency bands between 24.25 GHz and 86 GHz as strong candidates for the development of International Mobile Telecommunications, IMT-2020 (5G) systems [1]. The band 50.4 -52.6 GHz was identified as one of the possible frequencies. This had led to a huge interest in channel propagation characteristics in the millimeter wave band by the scientific community and industry, which pushed researchers to use or build new simulators that have not been validated against experimental measurements at these frequencies [2-4].

In this paper, channel propagation measurements in an outdoor scenario which combines buildings and a hilly terrain with vegetation are compared with ray tracing simulations carried out with a commercial software tool at 52 GHz. Even if the commercial tool used has not been validated at this frequency, the aim of the paper is to check the applicability of the tool and the possible improvements to take into account for this kind of channel prediction tools at these frequencies.

The measurement campaign, the scenario and the equipment are described in Section II. The simulations carried out with a commercial ray-tracing package are described in Section III. The measurement and simulation results are compared in Section IV. Finally, Section V includes the conclusions.

2. Experimental measurement campaign

The experimental measurement campaign was carried out on the Durham University Campus.

2.1 Channel Sounder

Durham University's sounder uses the chirp (FMCW) technique with heterodyne detection and covers a number of frequency bands with 3 GHz bandwidth at 30 GHz, 6 GHz bandwidth in the 50-75 GHz band and a maximum of 9 GHz bandwidth in the 60-90 GHz band. The time delay window is on the order of 819.2 µs which gives 1.2 kHz Doppler coverage for a single input single output configuration. The RF heads have 8 transmitters by 8 receivers for the 30 GHz band to enable MIMO measurements and angle of departure and angle of arrival measurements, and 2 transmitters by 2 receivers for the 50-75 GHz band and the 60-90 GHz band. Multiple bands and multiple site configurations for fixed links suitable for backhaul studies of atmospheric effects are enabled through the use of multiple receivers synchronized via GPS.

The detailed description of the sounder can be found in [5] with 2 by 2 multiple input multiple output results of path loss, delay spread and MIMO capacity. The 2 by 2 configuration enables both MIMO capacity estimation and dual polarized measurements using twists at the output of the transmitter or at the input of the receiver. This gives the cross-polar discrimination to be estimated. The transmitted power per channel is ~10 dBm and the dynamic range of the system was 120 dB. With horn antennas, having 20 dBi gain at the transmitter and at the receiver, the overall measured path loss is of the order of 155 dB for 20 dB signal to noise ratio.

2.2 Measurement scenario

Measurements were performed in an outdoor scenario with buildings to one side, a hill with trees on the other side, and a road passing in the middle and under a bridge connecting the two buildings. There are several metal structures in the environment such as: garbage containers, cars, street lamps, window frames, tubes, and the bridge structure. The buildings along the road have a brick facade and the farthest building to the transmitter has a flat plastic/metallic facade and two rain water drain pipes. Figure 1 shows the measured scenario. The transmitter antenna height is 3 m and the receive antenna is mounted on a rotator at 1.6 m height. The transmitter is placed close to the bridge and the receiver is placed in front of it. Measurements were done from a minimum separation of 4 meters, every 2 meters, up a maximum separation of 39 meters. For each point, the receiver antenna rotates

clockwise from 0° to 360°, and measurements are registered every 5°.
Figure 2 shows the power delay profiles (PDP) obtained at 0°, 90°, 180°and 270° rotation of the receive antenna, measured at a distance of 39 m. In the figure, the top left (TL) corresponds to a rotation of 0°, top right (TR) 90°, bottom left (BL) to 180° and bottom right (BR) to 270°.

Figure 1. Measured environment.

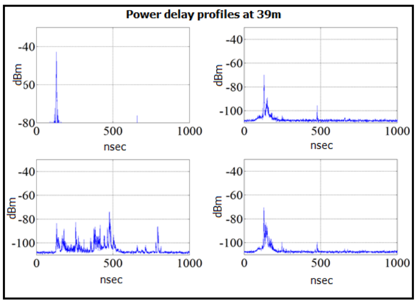

Figure 2. PDP with receiver at 39 m distance. Receiver rotated 0° TL, 90° TR, 180° BL, 270° BR.

The measurements show that for all receiver orientations, there are multipath rays with long time delays. Even when the receiver is rotated 180º i.e. facing away from the transmitter, there are rays reflected from the walls and objects that reach the receiver with considerable power values and excess time delays around 850 ns.

3. Simulations

The simulations were carried out with the Wireless InSite® software tool commercially available from REMCOM®. Wireless InSite® software offers efficient and accurate predictions of EM propagation and communication channel characteristics in complex urban, indoor, rural and mixed path environments [6]. The tool provides several ray-based propagation models that combine ray-tracing algorithms with the Uniform Theory of Diffraction.
The tool has two main drawbacks: it has not been validated against experimental measurements at millimeter wave band frequencies and the applicability of some models has frequency limitations. Even with these limitations, the tool has been used to do channel parameters estimation at millimeter wave band frequencies [4]. The work described in this paper is an exercise to check the applicability of the tool at these frequencies.

Figure 3. Site map from Google map

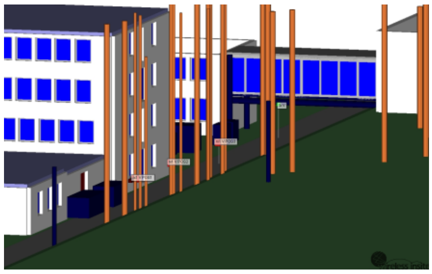

Figure 4. Simulated environment, side view.

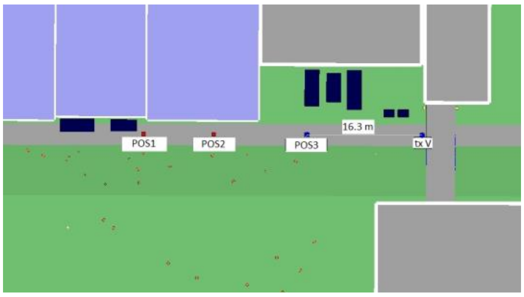

Figure 5. Simulated environment, top view

3.1 Simulation scenario

The simulated scenario was assembled using Google Maps in Figure 3. All the main elements were included: the slope of the terrain, buildings, metal objects as the frames in the windows, street lamps, drain-pipes, tubes under the bridge connecting the buildings, cars parked alongside the building and tree trunks. The foliage of the trees has not been included in the scenario due to the limitations of the biophysical model used in the simulation tool is only valid for frequencies up to 2 GHz.
The simulated environment is shown in Figure 4, the side view, and Figure 5, the top view. It can be seen from comparison with the Google map in Figure 3 and the pictures in Figure 1, that the scenario has been carefully reproduced. Metal objects are depicted in blue and tree trunks in brown. The small red boxes represent the receiver position, where POS1, POS2 and POS3 correspond to separation distances from the transmitter of 39, 29 and 16 m respectively. The transmitter is placed close to the bridge, in the same position as in the experimental measurements. In this paper only POS1, i.e. 39 m distance, is analysed.

3.2 Materials

The materials used in the simulations are: concrete, plaster board, single glass, double glazed windows, ceiling board, wood, chipboard, asphalt, wet ground and grass.
Characteristics of the materials at 52 GHz are calculated according to Recommendation ITU-R. P. 2040 except for the asphalt, wet ground and grass, where material characteristics at 1 GHz were used due to the unavailability of these material properties in the desired band. Therefore the reflection coefficient for these materials is unreliable for a correct estimation of reflected waves.

3.3 Antennas

The antennas used in the simulation were those used during the measurements, i.e. horn antennas of size (W x H x L) = 23x19.1x47.3 mm, with a maximum antenna gain of 20 dBi and 3 dB beamwidth of 18 °.

3.4 Simulation results

To reproduce the physical measurements of Figure 2, simulations at 39 m distance from the transmitter, at four angles of rotations of the receiver (0^o, 90^o, 180^o, and 270^o) were performed. The transmitted power was set to 10 dBm and the noise floor to -120 dBm.
Some differences between measurements and simulations are expected due to:

- trees and metallic objects are not millimetrically placed as in the real scenario,
- unavailability of dielectric characteristics of asphalt, grass and wet ground at 52 GHz
- foliage effects are not included,
- the simulator tool doesn't take into account the diffused multipath effect that a rough surface can contribute in the final results, as for example strong diffuse multipath components from a brick wall.

Figure 6 shows the normalized PDP simulated in vertical polarization for rotations 0^o, 90^o, 180^o, and 270.
When the receiver is rotated 0°, i.e. transmitter and receiver facing each other, we observe three groups of rays. The first group of rays, those with time of arrival within the 170 nsec, correspond to the LOS, relfection on the ground, diffraction from the wall and reflections from objects between the transmitter and the receiver. The second group of rays with longer time of arrival, around 250 nsec, is the group of rays that are reflected from the building, then the rays travel back and are reflected off the cars and garbage containers and then they arrive at the receiver. The third group, is the ray with the longest time of arrival, 740 nsec. It is reflected off the farthest building, it returns and is re-reflected from the metal structure of the bridge before arriving at the receiver after travelling 222 meters.

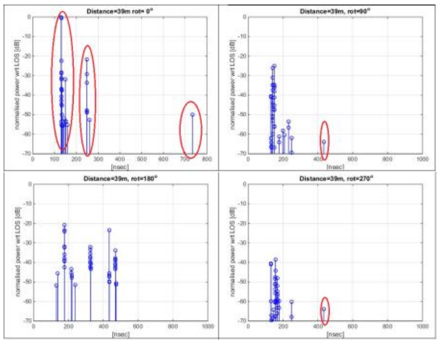

Figure 6. Simulated PDP. Receiver rotated 0° (TL), 90° (TR), 180° (BL), 270° (BR)

When the receiver is rotated 90°, it is pointing at the trees; it receives strong reflections from the trees, cars and street lamps.
When it is rotated 270°, it is pointing at the building; it receives strong reflections from the wall and the cars.
For both rotations, 90° and 270°, there is an isolated component at 440 nsec. This component corresponds to the ray that is reflected in the metal drainpipe of the farthest building, then in the street lamp, and finally in the car to arrive at the receiver.
When the receiver is rotated 180°, it is facing back the transmitter. In this case, reflections can be seen off the metal drainpipe of the farthest building, off the street lamps, off the cars, and off the building wall. All these rays arrive between 130 nsec and 475 nsec.

4. Comparisons

In this section, some of the differences between the measurements and the simulations are highlighted.

4.1 Rx rotated 0°

Figure 7 shows the results with receiver rotated 0^o, i.e. transmitter and receiver facing each other. It can be seen that some of the main components are correctly simulated, but the components between 200-300 nsec are predicted to have a considerably higher level than the measured response and the second far away component appears even farther away than the measurement and at a lower level (-50 dB with respect to the LoS component compared to -32 dB in the measurements). The simulation does not estimate the rays between 300 and 400 nsec.

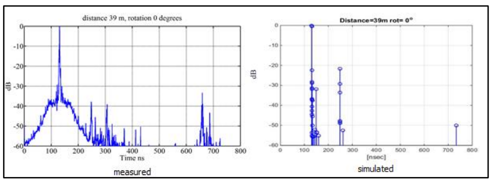

Figure 7. Measured(left) and simulated(right) PDP, rx rot 0°

4.2 Rx rotated 90°

Figure 8 shows the results with the receiver rotated 90°, i.e. receiver antenna pointing at the trees side. It can be seen that simulation generates well the first group or rays, the shape looks similar, but the rays seem spread with respect to the real measurements, as simulated rays arrive within 250 nsec instead of 175 nsec. The component at 440 nsec is generated by the simulator but with lower amplitude.

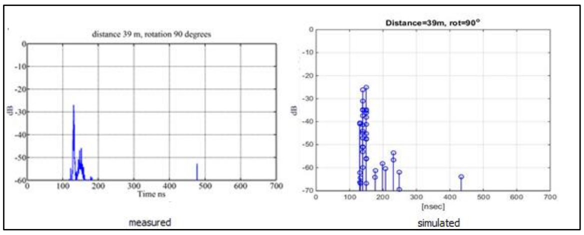

Figure 8. Measured(left) and simulated(right) PDP, rot 90°

4.3 Rx rotated 180°

Figure 9 shows results with the receiver rotated 180º, i.e., the receiver is facing away from the transmitter. The simulator does reproduce some of the rays arriving between 100 nsec and 500 nsec. However, there is a cluster of rays between 375-420 nsec that do not appear in the simulations. This could be due to diffused multipath components arising from scattering off rough surfaces that the simulator does not model. Some of the simulated amplitudes are 10 dB higher than the measurements.

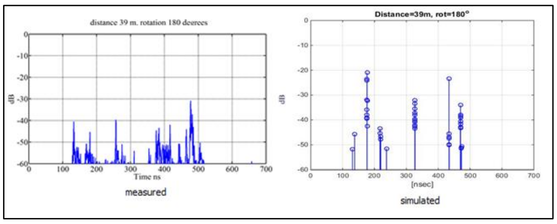

Figure 9. Measured(left) and simulated(right) PDP, rot 180°

4.4 Rx rotated 270°

Figure 10 shows the results with the receiver rotated 270°, i.e., receiver antenna poiting at the building side.
It can be observed from the figure, that the simulation in this case caputres the first group of rays within the 200 nsec, with rays around 150 nsec are generated with 10 dB higher amplitude. The other two components at 250 nsec and 440 nsec are also well generated, but with 10 dB difference between the simulated and the measured channel impulse reponse amplitudes.

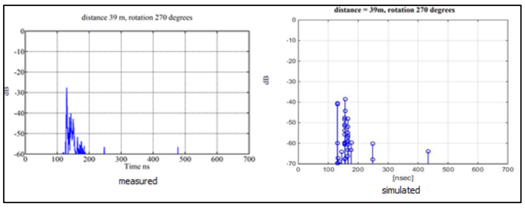

Figure 10. Measured(left) and simulated(right) PDP, rot 270°

5. Conclusions

Channel propagation experimental measurements and ray-tracing simulations at 52 GHz are compared for an outdoor site combining: buildings, hilly terrain with trees, and metal objects such as cars, street lamps, garbage containers, drainpipes and window frames.
Measurements and the simulations show that long range reflections from metallic structures, even 100 m far from the transmitter, contribute significantly to the received multipath components.
While the simulator predicts the main features of the channel, the relative magnitudes of the multipath components are inaccurate. The simulation does not predict the cluster of rays accompanying the strong multipath, that sometimes appear in the measurements, these could be diffused multipath components arising from rough surfaces. The impact of these components can be significant in the estimation of channel parameters such as the time delay spread and the received power.
However, refinement of the simulated scenario improved the accuracy of the results.
To reproduce the characteristics of the propagation channel, the simulator requires reliable data on material properties, and needs to calculate foliage effects and scattering effects of rough surfaces. Further calibration of such tools is therefore necessary prior to their application as channel prediction tools.

6. References

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[6] Remcom Inc, "Wireless InSite® Reference Manual".