# MILLIMETER WAVE BAND PROPAGATION STUDIES FOR 5G NETWORKS

**S. Salous**

Centre for Communication Systems, Durham University, Durham DH1 2BD

sana.salous@durham.ac.uk

***Abstract:*** Several frequency bands in the range 24-86 GHz have been identified by WRC15 as possible frequencies for future 5G radio networks. To evaluate the radio channel in these bands, Durham University performed propagation studies in three of these frequency bands using the state of the art multiband Durham channel sounder. Using two transmit and two receive channels in each band, dual polarised measurements of typical indoor and outdoor environments were analysed to estimate a number of channel parameters such as path loss, delay spread and cross polar discrimination. Results of both directional and omni-directional measurements will be presented outlining contributions to the recommendations of the international telecommunications union.

## INTRODUCTION

To meet the increasing demand for higher data rates the world Radio-communications conference in 2015, WRC15, identified several frequency bands in the range 24-86 GHz with different bandwidths. A total of seven frequency ranges with bandwidths from 1.6 GHz in the 31.8-33.4 GHz to 10 GHz from 66-76 GHz to extend the 60 GHz ISM band were selected. This led to administrations and standardisation bodies such as 3GPP and the International Telecommunications Union (ITU) to encourage propagation studies and channel modelling in these bands in preparation for WRC19 when future frequency allocation for 5G radio networks will be discussed.

To characterise the radio channel in four of the WRC15 bands, 24.25-27.5 GHz, 50.4-52.6 GHz, 66-76 GHz and 81-86 GHz, the state of the art 2 transmit by 2 receive channel sounder initially developed at Durham University to cover the 60 GHz ISM band (58-64 GHz) [1] was upgraded with a new programmable IF unit and several radio frequency heads using frequency multipliers. These were either dual transmit and dual receive units or single receive units with additional RF front end amplification to enable the use of low gain omni-directional antennas. The new units enable the generation of bandwidths up to 3 GHz in the 25-31 GHz band, 6 GHz in the V band (50-75 GHz) covering two of the WRC15 frequency ranges (51-57 GHz and 67-73 GHz), and up to 9 GHz in the E band (60-90 GHz).

Two types of measurements are enabled with the sounder(s): fixed link point to point or point to multipoint, and point to area (base station to user) as in typical mobile radio scenarios. The single and dual RF heads enable dual polarised transmission and reception, and dual polarised transmission and single polarisation reception. The fixed link multipoint reception monitors the weather effects on the millimetre wave such as the impact of rain on attenuation, scattering and interference and narrow pulse distortion which might limit the data rate. This is associated with the monitoring of rain size, rain rate etc.. with a high end disdrometer. The fixed link study uses RF heads in the 25-28 GHz and in the E band (75-84 GHz) while the point to area measurements target three bands: 25.5-28.5 GHz, 51-57 GHz and 67-73 GHz.

In this paper we present an overview of the sounder. This is followed by typical results of measurements performed in the point to area scenarios with directional dual polarised antennas at the transmitter and receiver and directional dual polarised antennas at the transmitter and vertically polarised omni-directional antennas at the receiver. Typical path loss model parameters and delay spread values are presented.

## Overview of channel sounder and measurement environment

Paper [1] describes the original sounder design which has an IF unit that up converts the frequency to a fixed IF at 14.5-16 GHz. Using a times four frequency multiplier the unit was used to generate frequencies in the ISM band between 58-64 GHz. To enable the generation of a wider range of frequencies, a new IF unit was assembled which follows the same architecture but employs a programmable synthesiser to generate the local oscillator which enables the generation of the IF signal between 12.5-18.5 GHz. Used in conjunction with frequency multipliers this provide the ability to cover a wide range of frequency bands. Fig. 1 shows a typical set up for the dual band measurements performed with 3 GHz bandwidth between 25.5-28.5 GHz and 6 GHz between 51-57 GHz. At the transmitter a 2 way switch is used in the RF heads for dual polarisation transmission and a 2 way splitter at the receiver for simultaneous reception. The technique enables bandwidth compression thereby allowing the use of a relatively low sampling rate data acquisition card. The set up was used in a number of field trials indoor and a typical suburban environment outdoor (see Fig. 2) with directional antennas (dual polarisation) at the transmitter. At the receiver either two directional antennas with a rotator to cover all azimuthal angles (dual polarised measurements) were used in conjunction with the dual channel receivers or omni-directional antennas were used for the single receiver set up. To cover all three frequency bands, each measurement route was covered twice: once for the dual band measurements and a second time for the higher frequency band of 67-73 GHz.

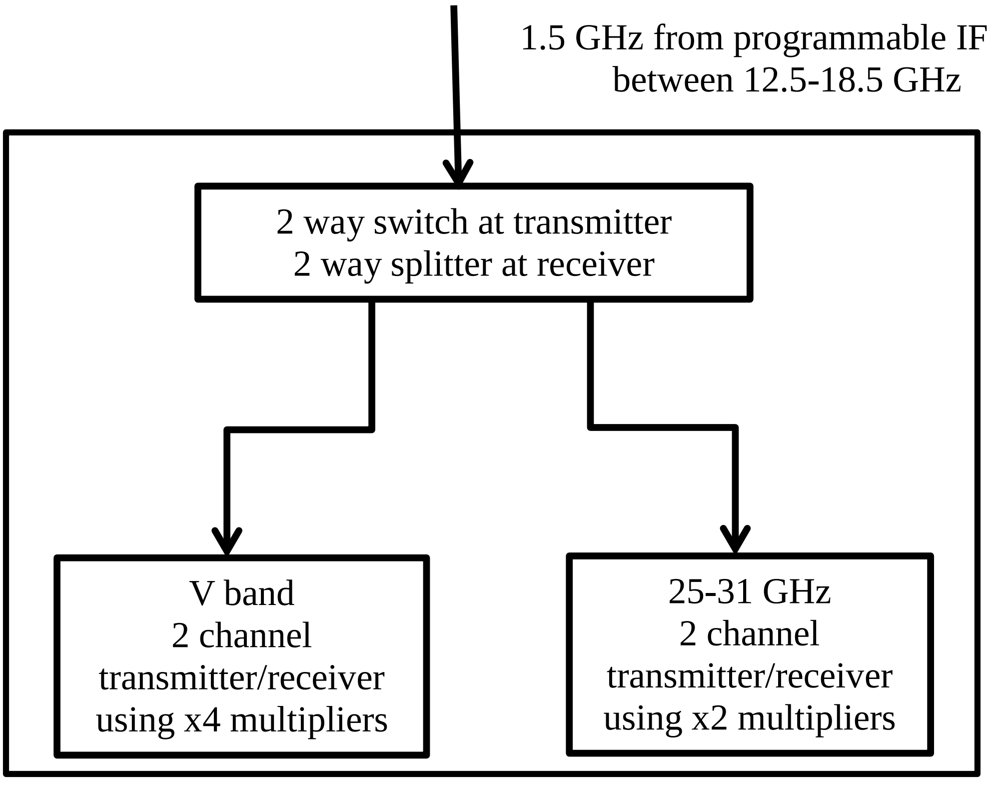


Fig. 1 Block diagram of two transmit by two receive architecture


Fig. 2 Outdoor suburban environment

# Typical measurement results

Fig. 3 is an example of the received power versus angle of rotation estimated from the dual polarised measurements in below the rooftop outdoor scenario.

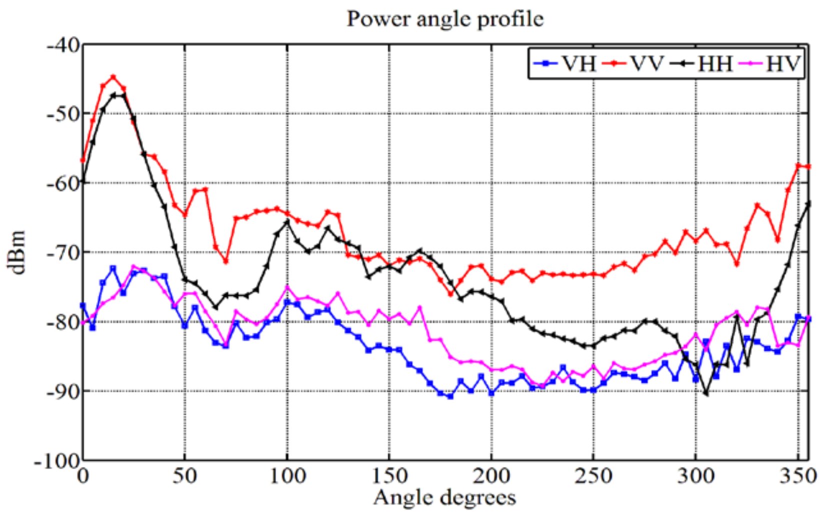


Fig.3 Received power versus angle of rotation for dual polarised measurement in the 67-73 GHz band

The data were analysed to estimate a number of channel parameters including path loss model parameters based on equation (1) for each band.

$$PL(d,f)=10\alpha \log 10(d)+\beta+N(0,\sigma) \text{ dB} \quad (1)$$

Table 1 gives an example of these parameters in the 67-73 GHz band for three different possible antenna orientations and beam widths. The first represents the model for the line of sight (LOS) component, whereas the second and third columns represent the synthesised omni-directional model where the power from all angles was added and the third column for the synthesised power from a 320 degree beam width which excludes the LOS and the angles around the LOS component. The table indicates that for the vertical to vertical (VV) polarisation, the path loss model parameters for the strongest beam and for the synthesised omni-directional antenna, are fairly close to the free space loss parameters which are 2 for α and 69.34 for β at 70 GHz. This indicates that the outdoor environment was dominated by a line of sight component and reflections from the buildings' façade contributed small amounts of received power in comparison to the LOS component as can be seen from Fig. 3. Comparing β for the cross-polarised transmission, (VH and HV) the loss increases in excess of 20 dB than for the co-polarised wave. Considering the VV polarisation the path loss from the back beam has an additional 15.3 dB loss (84.4 in comparison to 69.1) in comparison with the synthesised omni which limits the dynamic range of the receiver.

Table 1: path loss parameters for outdoor environment in the 67-73 GHz band

| **Antenna polarisation** | **Strongest beam** | **Synthesised omni** | **Synthesised 320$^{o}$ back beam** |
|---|---|---|---|
| | α β | α β | α β |
| **VH** | 1.74, 98 | 1.89, 93.6 | 2.12, 91.9 |
| **VV** | 2.16, 68.8 | 2.11, 69.1 | 1.72, 84.4 |
| **HH** | 1.98, 71.8 | 1.85, 73.9 | 1.24, 95.5 |
| **HV** | 1.42, 101.8 | 1.73, 94.6 | 2.00, 96.2 |

While the rotational measurements provided insight into the received power for beamforming antennas as anticipated in the millimetre wave band, the time taken to perform the rotation limits the number of locations that can be measured and the estimation of the spatial consistency of the channel. This limitation is overcome either by using an omni-directional antenna with a single channel receiver or a multiple receiver architecture that covers the azimuthal plane with multiple directional antennas. These approaches allow the spatial movement of the receiver while acquiring data. In this study, a single receiver with an omni-directional antenna was used to enable the acquisition of continuous measurements. Measurements were performed in the same environment of Fig. 2 which is a typical suburban environment in the three frequency bands as illustrated in Fig. 4 for a LOS scenario. The path loss parameters were then evaluated using the frequency dependent path loss model given by equation 2 and the parameters, α, β, ϒ and σ were estimated.

$$PL(d,f)=10\alpha \log10(d)+\beta +10\gamma \log10(f) +N(0,\sigma) \text{ dB} \quad (2)$$

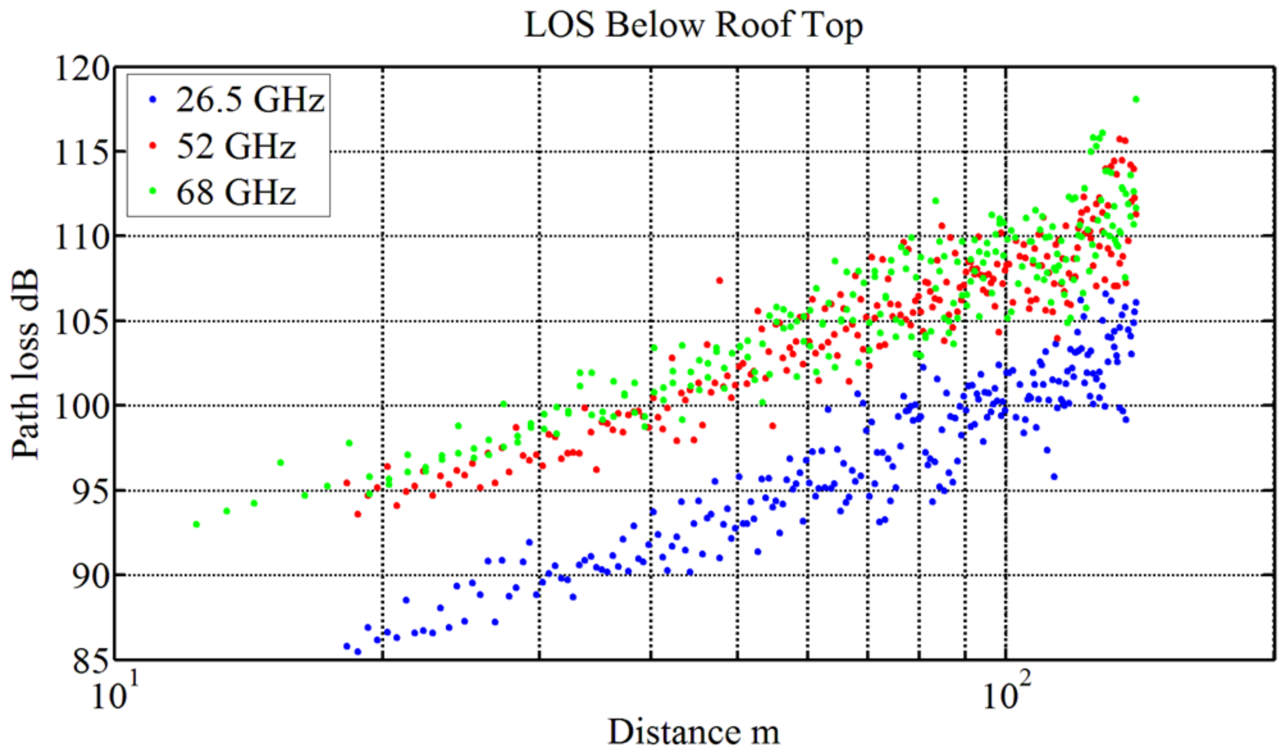

Fig. 4 Path loss versus distance for three frequency bands

Typical values for the parameters for different environments were estimated by combining measurements from different administrations and the results are now published in ITU-R 1411-9 tables 4, 7 and 8 [2].

Other parameters that were estimated include the rms delay spread. Table 2 gives some typical values for the vertical to vertical polarisation at two frequencies for both LOS and NLOS outdoor scenarios. The full table can be found in ITU-R 1411-9 tables 11 and 13 [2] for the outdoor environments and ITU-R 1238-9 [3] for the indoor environments.

Table 2. RMS delay spread values for 20 dB threshold for outdoor environments

| **Measurement conditions** | | | **r.m.s. delay spread (ns)** | |
|---|---|---|---|---|
| | Scenario | f (GHz) | 50% | 95% |
| **Below roof top** | LoS | 27 | 3.5 | 43.6 |
| | NLoS | | 13.4 | 30.3 |
| | LoS | 70 | 2.6 | 36 |
| | NLoS | | 10 | 23.7 |

## CONCLUSION

Wideband dual polarised measurements were performed using state of the art multiple band channel sounder at Durham University. Data were collected using different types of antennas below roof and above rooftop with directional dual polarised antennas as well as single receive omni-directional antennas in three of the frequency bands identified by WRC15. The data were analysed to estimate path loss parameters and rms delay spread. These were submitted to the ITU and included in two recommendations.  For the full results consult ITU-R 1411-9 and ITU-R 1238-9.

## REFERENCES


1. Salous, Sana, Feeney, Stuart, Raimundo, Xavier & Cheema, Adnan (2016). Wideband MIMO channel sounder for radio measurements in the 60 GHz band. IEEE Transactions on Wireless Communications 15(4): 2825-2832.

2. ITU-R 1411-9, https://www.itu.int/rec/R-REC-P.1411-9-201706-I/en

3. ITU-R 1238-9, https://www.itu.int/rec/R-REC-P.1238/en