



# WaveComBE

mmWave Communications in the Built Environments

## WaveComBE\_D2.4

Technical Documents to be submitted to  
the ITU for incorporation in ITU-R P.1411  
and ITU-R P. 1238

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<sup>1</sup> CO = Confidential, only members of the consortium (including the Commission Services)

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## Executive Summary

This document describes the five technical documents submitted to Study Group 3 (SG3) of the International Telecommunications Union (ITU). When the proposal was prepared it was envisaged that the output would be relevant to ITU-R P. 1238 and ITU-R P. 1411. However, while the indoor results generated in the project were relevant to ITU-R P. 1238, the outdoor results were more relevant to ITU-R P. 2108 and ITU-R P. 530 and to the databank of the SG3. Contributions to ITU-R 1411 were also made; however, outside the WAVECOMB project.

Thus, the contributions to SG3 of the ITU, consisted of five documents. These included two inputs to update ITU-R 1238-10 with one input submitted to the August meeting, 2020 which describes the measurement data across nine different frequency bands in indoor environments. The data were subsequently combined with data from other administrations to develop a new site general indoor model in three environments: office, corridor and industrial environments. A second input was submitted to SG3 in June 2021 with wideband channel parameters. The new model and the channel parameters were approved in the SG3 meeting in June 2021 and will be included in ITU-R 1238-11, in due course. An information document which presented results of base station to user in an outdoor cluttered environment at 26 GHz was submitted to the SG3 meeting in August 2020 with the measurement data to be added to the databank of SG3. Two other inputs were submitted to the SG3 meeting June 2021: one document contains weather statistics tables for 2020 to include in the ITU databank and a second input to modify ITU-R P.530. Both inputs have been approved. This deliverable gives an overview of these five inputs of the WAVECOMB project.

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## List of Acronyms and Abbreviations

ITU: International Telecommunications Union

SG3: Study Group 3

Rms: Root mean square

## 1. Input to ITU-R P. 1238

This section gives the details of the two submitted inputs to modify/include in ITU-R 1238 P. 1238-10

### 1.1 Input on measurements and modelling of indoor environments

A document entitled “Multi-band measurements in various indoor environments” was submitted to the SG3 meeting in August 2020 towards the development of the new site general model. The document presented the results of extensive multi-frequency channel measurements, covering nine frequency bands within the 0.6-73 GHz range in several indoor environments using the Frequency Modulated Continuous Waveform (FMCW) channel sounder developed at Durham University. The document presented model parameters similar to the model adopted in Recommendation ITU-R P.1411-10 which provides path loss coefficients based on the alpha-beta-gamma (ABG) model across a large frequency range for the measured indoor scenarios. The following details the input to the SG3 meeting.

#### Multi-band indoor measurements

The state of the art, Durham University’s channel sounder is used to conduct multi-frequency wideband indoor measurements. The measurements were performed at the science site campus of Durham University in typical office environments, a computer laboratory and a computer foyer, corridor and factory environment as shown in Fig. 1(a)-(e), with the measurements layout as shown in Fig. 2 (a)-(g). The measurements were performed in sub 1 GHz, 2 GHz, 5 GHz, 15 GHz, 18 GHz, 25 GHz, 39 GHz, 60 GHz and 70 GHz with a sweep rate of 1.22 kHz. In each measured environment the transmitter (Tx) is set at a height between (2.2-2.6 m) depending on the ceiling height of the measured scenario while the receiver (Rx) is fixed at (1.5-1.6 m). These measurements were conducted at different locations in line-of-sight (LoS) and non-line-of sight (NLoS) scenarios. An omni-directional antenna is employed at the Tx and Rx. The data were recorded for one or two-seconds duration with 40 MHz sampling rate ADC. Table. 1 provides a summary of the conducted channel measurement set-up parameters. In each scenario between 36 and 132 Rx locations were measured and the corresponding Tx-Rx distances were (~5-35 m).

FIGURE 1

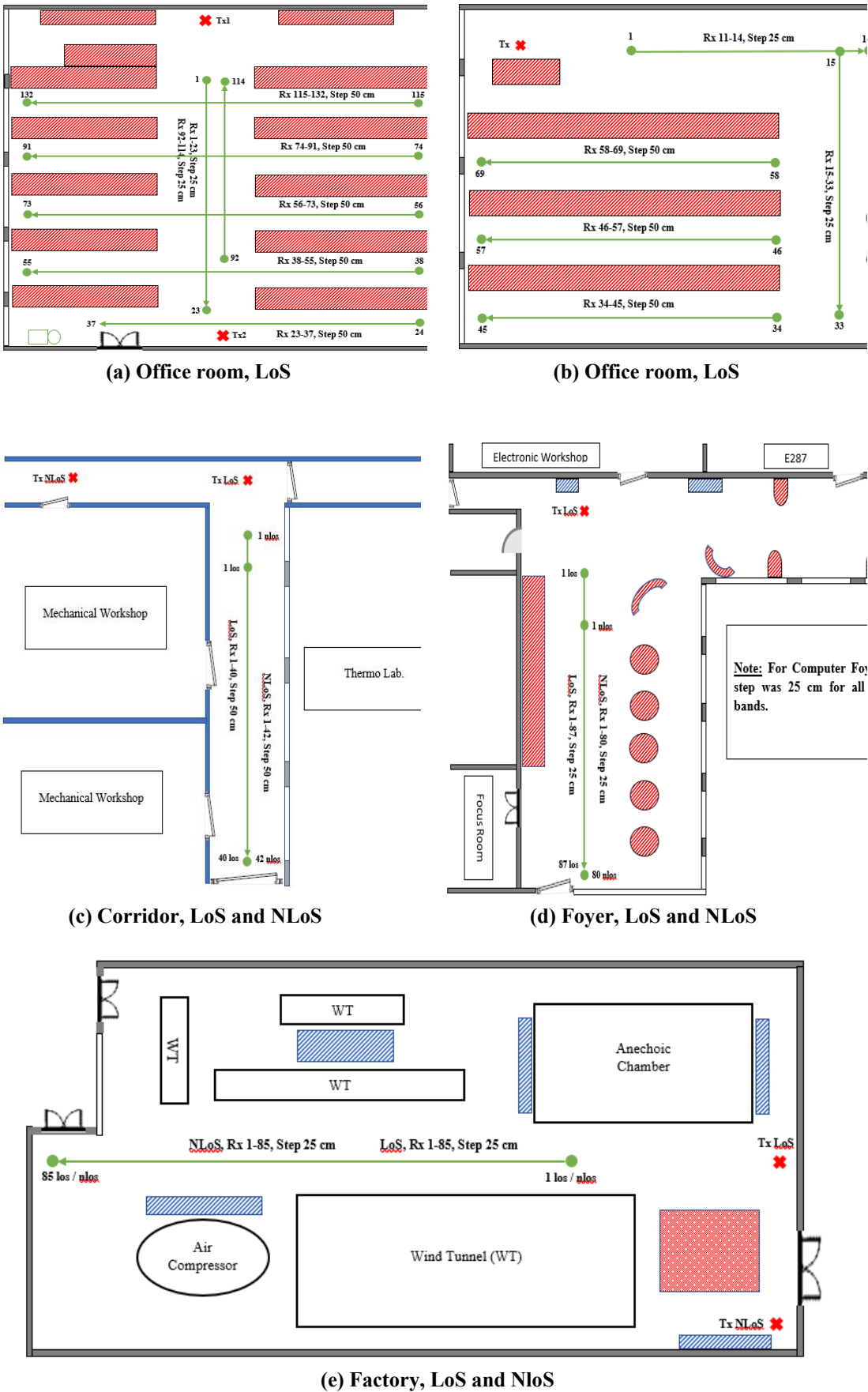
Measurement environments:(a) Office room, (b) Corridor (c) Computer Lab., (d) Factory, (e) Foyer.

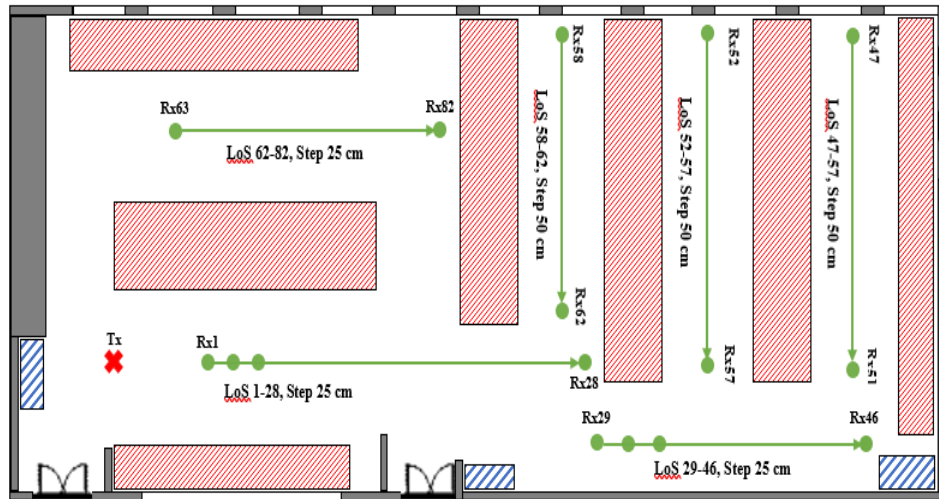




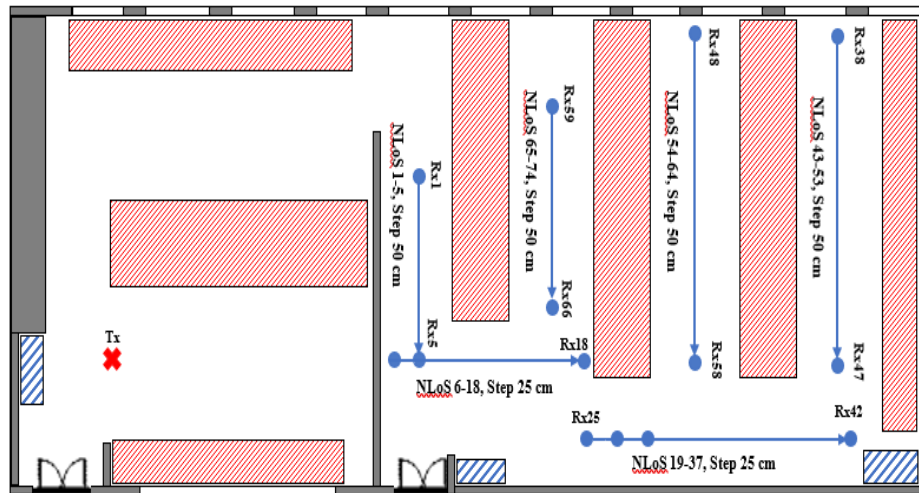
FIGURE 2

Map showing location of transmitter and path followed by the receiver





(f) Computer Lab., LoS



(g) Computer Lab., NLoS

TABLE 1  
Sounder unit set-up parameters

Frequency band (GHz)	0.25-1	2.28-2.53	4.56 – 5.06	14.9 - 16.4	16.82 - 18.32	25.32 - 28.32	36.06-40.56	59.6 - 65.6	67.28 - 73.28
RF bandwidth (GHz)	0.75	0.25	0.5	1.5	1.5	3	4.5	6	6
Analysis bandwidth (GHz)	0.25	0.25	0.5	1	1	1	1.5	2	2
Transmit antenna	Omni-directional								
Receive antenna	Omni-directional								
Transmit antenna height	2.2-2.6 m								
Receive antenna height	1.5-1.6 m								

Results of path loss

The measured data were processed with a bandwidth between (0.25-2 GHz) depending on the measured frequency bands to obtain the power delay profiles. Figure 3 (a)-(b) shows an example of the computed power delay profile for the corridor environment for both the LoS and NLoS scenarios. Following calibration the path loss parameters were estimated as shown in Figure 4 for the corridor environment. The multi-frequency model coefficients (ABG model) were also estimated and applied for the different indoor environments. Table 2 summarizes the results.

FIGURE 3  
Power delay profiles for corridor, (a) LoS scenario (b) NLoS scenario

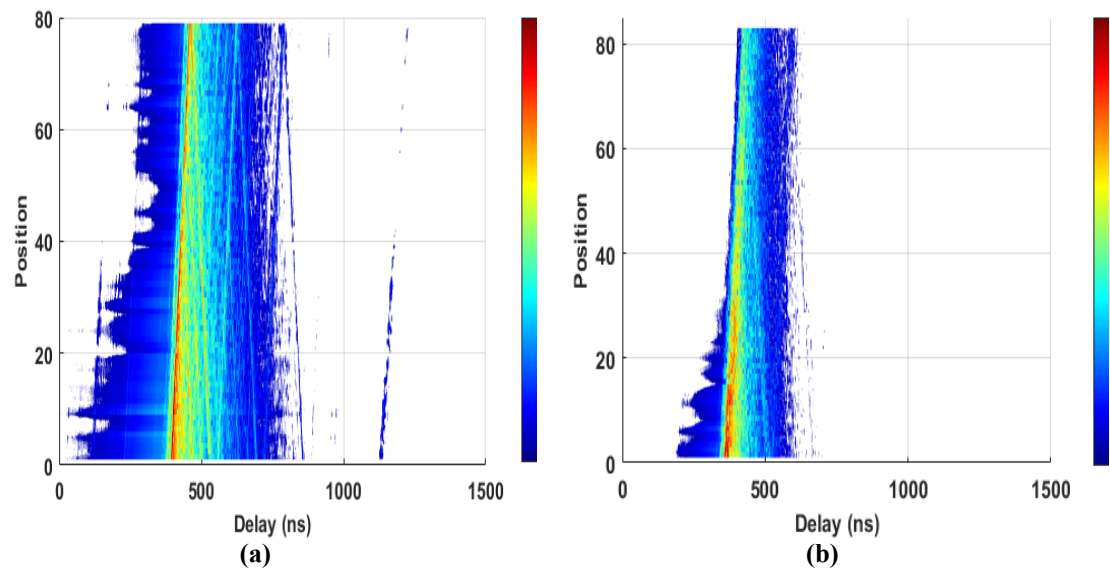


FIGURE 4

Measured path loss vs. distance for the ABG model fit for corridor: (a) LoS, (b) NLoS

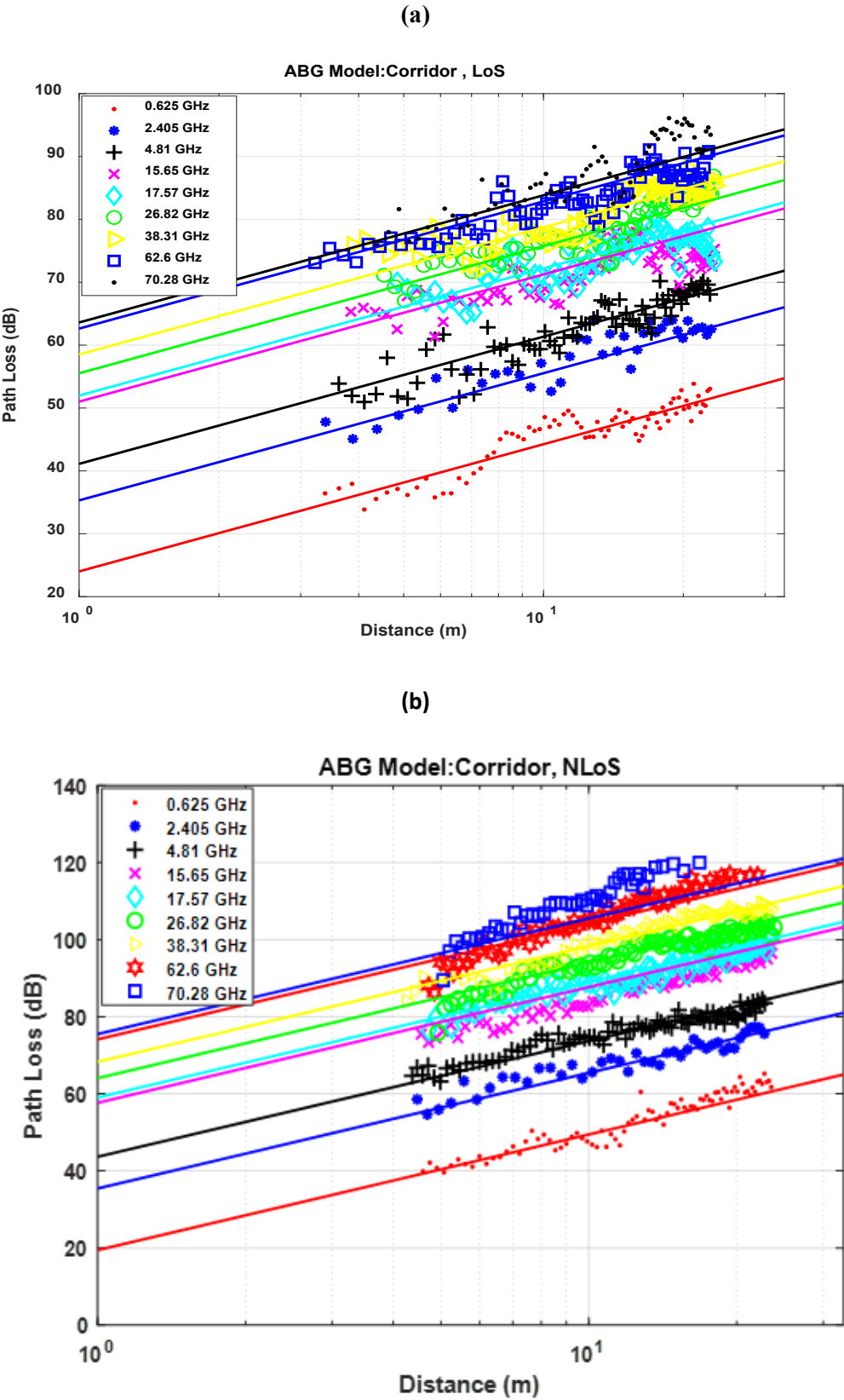


TABLE 2  
Estimated model parameters

Frequency range (GHz)	Distance range (m)	Type of environment	LoS/NLoS	$\alpha$	$\beta$	$\gamma$	$\sigma$
0.6-73	3.8-24	Corridor A	LoS	2.02	27.9	1.93	2.56
0.6-73	4.6-24	Corridor A	NLoS	3	25	2.73	2.64
0.6-73	4.4-23	Corridor B	LoS	1.33	32	2.05	3.26
0.6-73	3.9-11	Office 1	LoS	0.822	34.7	2.22	1.88
0.6-73	3.5-8.5	Office 2	LoS	1.09	32.7	2.17	2.36
0.6-73	2.9-18	Computer Lab.	LoS	2.03	29.5	1.94	3.18
0.6-73	6.7-17	Computer Lab.	NLoS 1 and 2	1.77	33.3	2.64	5.21
			NLoS 1	2.13	28.4	2.91	5.3
			NLoS 2	1.65	34.9	2.41	3.58
0.6-73	5.3-26.7	Foyer	LoS	1.54	33.7	1.89	3.28
0.6-73	14.4-29.4	Foyer	NLoS	4.57	5.9	2.11	4.22
0.6-73	9.3-30.9	Factory	LoS	2.09	25.4	2.12	2.49
0.6-73	10.9-31.8	Factory	NLoS	2.21	29.1	2.2	2.27

These measurements were provided to support the further development of Recommendation ITU-R P.1238 and the ongoing work within CG 3K-6 in establishing the ABG model parameters for indoor environments. The data from three environments: corridor, office and industrial environments were all combined with measurements from several other administrations and were used in the development of the new model. Details of the contributions will appear in ITU-Report ITU-R P.2406. The data from the Conference environments will be used in the future development of further indoor environments pending contributions from other administrations. The developed model and its verification weren't carried out in collaboration between ETRI, Korea and Durham University.

## 1.2 Input on wideband channel parameters

Following the input submitted to the SG3 meeting in August 2020, the *rms* delay spread was estimated from the wideband channel measurements outlined in the input described in section 1.1. A document was submitted to propose the values for power delay profiles with a 20 dB threshold for all the scenarios that satisfied the criterion.

The document included a table for all the estimated parameters across the nine frequency bands for both line of sight and non-line of sight scenarios. Table 4 identified frequency bands in Table 5 in recommendation ITU-R P. 1238-10 which do not have values with omni-directional antennas and it was proposed that these values are included in the recommendation. The document was approved, and the values will be added to Table 5 of the updated recommendation ITU-R P.1238-11 in due course.

TABLE 3  
Estimated *rms* delay values

Freq. GHz	Corridor		Conference room	Computer Cluster	
	LoS (10%, 50%, 90%)	NLoS (10%, 50%, 90%)	LoS (10%, 50%, 90%)	LoS (10%, 50%, 90%)	NLoS (10%, 50%, 90%)
<b>14.9-16.4</b>	(4.7, 12.9, 23.7)	(7.2, 11.4, 16.3)	(12.36, 16.53, 20.63)	(5.3, 20.5, 33.5)	(12.6, 21.6, 26.5)
<b>16.82 - 18.32</b>	(3.8, 11.9, 19.8)	(6.5, 11.8, 18.3)	(12.16, 18.73, 23.56)	(4.7, 13.4, 25.9)	(13.3, 21.3, 26.3)
<b>25.3-28.3</b>	(3.7, 11.6, 16.9)	(5.9, 12.0, 17.4)	(13.83, 17.56, 21.80)	(6.5, 14.7, 29.3)	(13.1, 19.0, 23.6)
<b>36-40.5</b>	(5.8, 13.2, 23.1)	(4.0, 13.2, 19.8)	(10.84, 15.21, 18.97)	(6.5, 17.0, 31.0)	(10.7, 16.7, 22.3)
<b>59.6-65.6</b>	(1.7, 2.6, 4.7)	-----	(8.76, 13.17, 17.45)	(2.5, 6.8, 16.4)	-----
<b>67.3-73.3</b>	(1.7, 7.6, 14.9)	-----	(7.59, 13.71, 20.06)	(5.8, 15.0, 30.3)	-----

Freq. GHz	Factory		Office	
	LoS (10%, 50%, 90%)	NLoS (10%, 50%, 90%)	LoS (10%, 50%, 90%)	NLoS (10%, 50%, 90%)
<b>14.9-16.4*</b>	(4.4, 11.6, 19.4)	(18.0, 23.3, 28.1)	(9.7, 17.5, 25.5)	(12.3, 17.8, 23.2)
<b>16.8-18.3*</b>	(4.7, 8.5, 15.4)	(17.5, 22.9, 28.9)	(9.9, 18.5, 24.9)	(13.3, 21.6, 27.7)
<b>25.3-28.3*</b>	(5.3, 9.5, 15.6)	(15.9, 22.5, 28.5)	(9.4, 15.3, 20.9)	(8.6, 16.0, 21.2)
<b>36-40.5<sup>!</sup></b>	(5.8, 9.3, 14.5)	(15.7, 19.8, 25.2)	(5.6, 9.7, 17.1)	(9.8, 12.6, 16.7)
<b>59.6-65.6<sup>#</sup></b>	(5.5, 7.4, 12.5)	(5.5, 11.6, 21.7)	(5.1, 8.7, 20.9)	(3.5, 10.1, 17.9)
<b>67.3-73.3<sup>#</sup></b>	(4.4, 11.1, 17.3)	(6.2, 14.7, 22.8)	(3.2, 7.0, 13.6)	(5.9, 9.1, 16.8)

Antennas: Transmitter and Receiver omnidirectional, Bandwidth: \* 1 GHz, <sup>1</sup>1.5 GHz, <sup>2</sup>2 GHz

## 2. Input to ITU-R 2108

In WRC-19, the frequency band around 26 GHz has been identified as one of the bands for 5G, to be harmonised in Europe. Recommendation ITU-R P.2108-0 gives the clutter loss versus distance for distances greater than 0.25 km. To verify the applicability of the recommendation for shorter distances, an information document was presented to the SG3 meeting in August 2020, of results of clutter loss measurements at 26 GHz using the wideband channel sounder of Durham University on the Science site over short distances on the order of 50-105 meters. The Recommendation ITU-R P.2108-0 statistical clutter loss model is applied to model the clutter loss, and the cumulative distribution function (CDF) of the measured and modelled clutter loss show good agreement.

**Clutter loss measurements:** The custom-designed Frequency Modulated Continuous Waveform (FMCW) channel sounder was used to conduct 26 GHz clutter loss measurements along three routes at Durham University, indicated as (R1), (R2), and (R3), shown in Fig. 5(a)-(c). The Tx is placed at a height of about 18.2 m with a down tilt angle of 12°, as shown in Fig. 5(d). The measured frequency band is 24.68-27.68 GHz with a sweep repetition frequency of 1.22 kHz. A horn antenna with 20 dBi gain and 18° beamwidth is used at the Tx side, while an omnidirectional antenna is used at the Rx side with a height of 1.6 m. The main beam of the Tx antenna is adapted to cover the three measurement routes, as shown in Fig. 6. Three routes R1, R2 and R3 were measured with distances of 50-80 m, 60-100 m, and 100-105 m for the three routes, respectively.

FIGURE 5

**Measurement environment for clutter loss (a)-(c) measurements routes, (d) transmitter location**

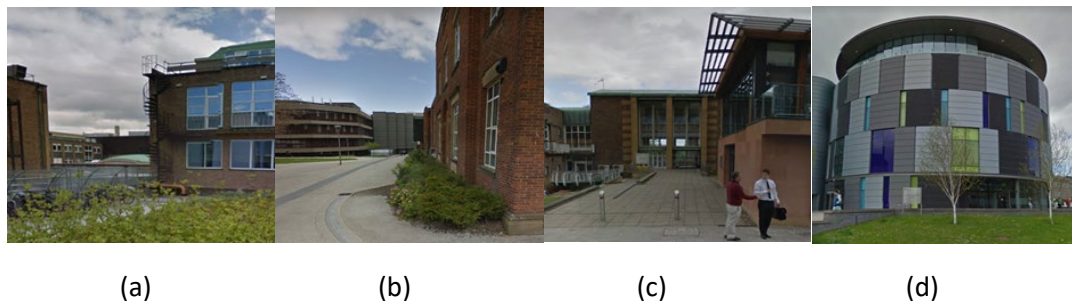
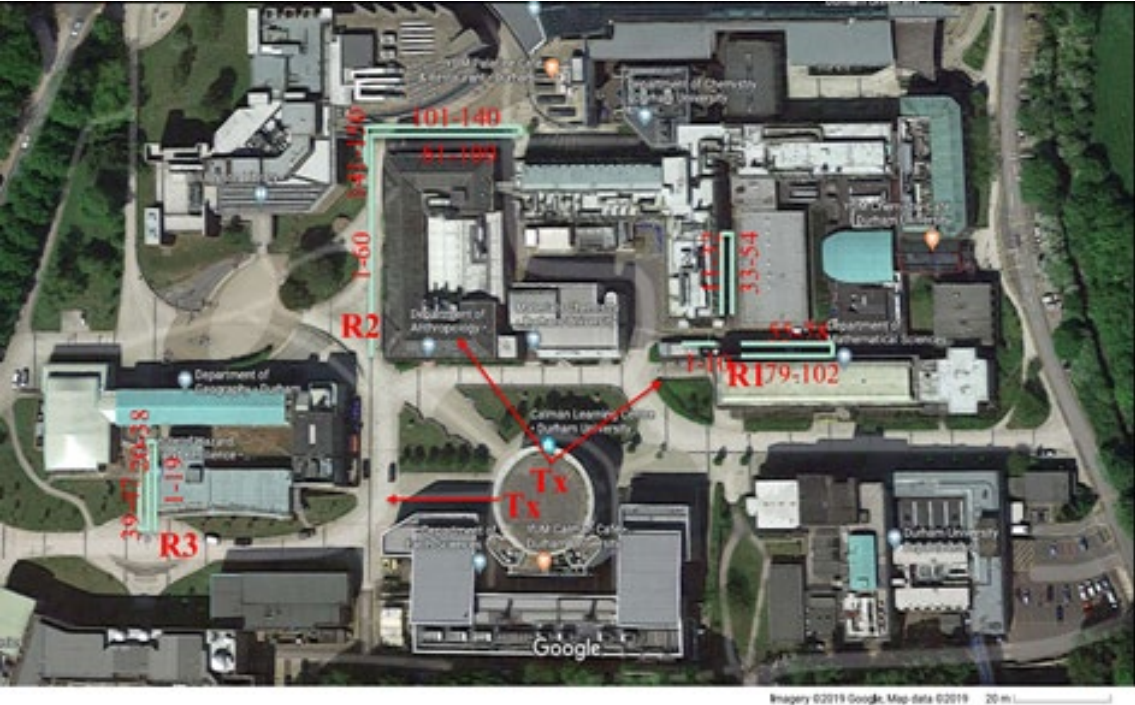




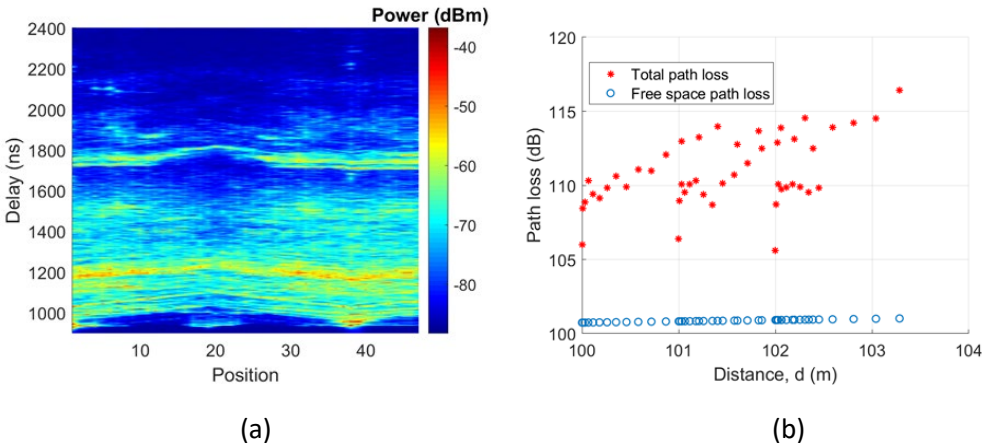
FIGURE 6  
Map showing location of transmitter and path followed by the receiver



Results of clutter loss

The data were processed with 1 GHz bandwidth to obtain power delay profiles as shown in Figure 7.a for R3. Following calibration, the path loss was estimated and compared with free space loss as shown in Figure 7.b.

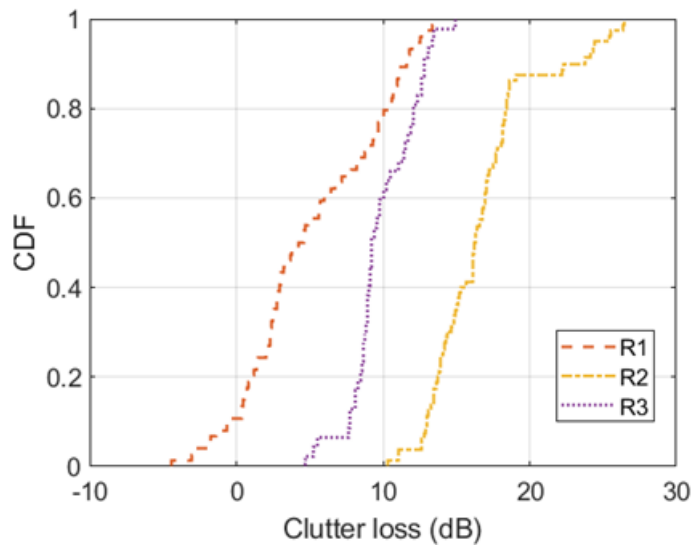
FIGURE 7  
(a) Power delay profiles for R3, with (b) corresponding path loss vs distance





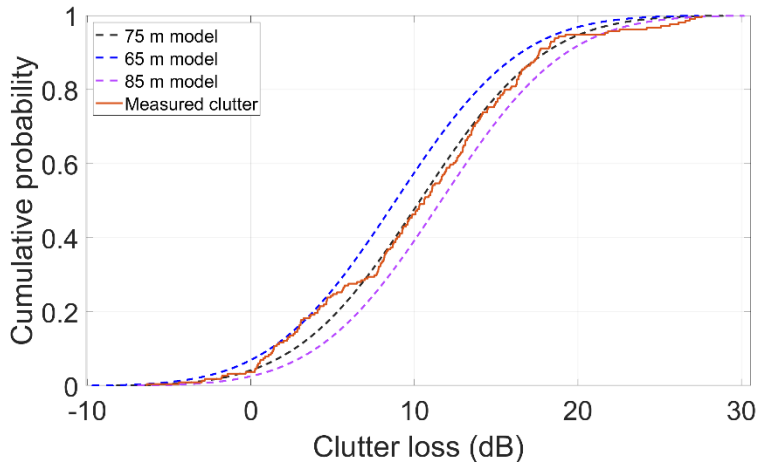
The cumulative distribution of clutter loss for the three routes is shown in Figure 8 where the different routes exhibited different clutter loss values.

FIGURE 8  
CDF of clutter loss per route



The CDF of all the three routes was then combined and compared with the CDF from the clutter loss model in the recommendation for distances 65 m, 75 m and 85 m as in Figure 9 where it can be seen that the measured clutter loss is closest to the statistical clutter model when  $d = 75$  m. The measured median clutter loss is 10.61 dB, which is comparable with the statistical clutter model of 10.34 dB when  $d = 75$  m which corresponds to the median value of the measured distance. The comparison shows a good match between measured and modelled clutter losses.

FIGURE 9  
CDF of measured and modelled clutter loss



## Conclusions

The clutter loss model was derived for distances greater than 250 m. However, the measurements show that the model is also applicable for distances between 50-105 m which are typical ranges for 5G cells operating in the millimetre wave band. The measurements data were also submitted to the databank of the SG3.

## 3. Input to ITU-R P. 530

A document entitled 'FIXED LINK LONG-TERM MEASUREMENTS' was submitted to the SG3 meeting in June 2021. The document described the experimental set up of the fixed link which consists of three links: one direct link and a side non-line of sight link at two frequency bands: 25.84 GHz and 77.54 over a 36 m link and a second link using a Filtronic transceiver over 200 m at 77.125 GHz as in Figure 10. More details are presented in Deliverable 2.3.

The ITU document presented the experimental set up, the weather station used in the measurements and rain attenuation versus rain fall rate. Figure 11 presents an example of the presented rain attenuation vs rainfall rate and snow grains.

Based on the measurements at Durham University, application of the maximum recommended value of the distance factor  $r$  equal to 2.5 in the recommendation, which was mainly derived from long-range measurements, was demonstrated not to be applicable for short-range links as shown Figures 12 a-f. Figure 12 shows a full and detailed comparison between the measured and ITU predicted rain attenuation, with and without using the maximum recommended distance factor  $r$  of 2.5 for the E (77 GHz) band, for selected predominant rain events. The figure shows that application of the 2.5 restriction of the distance factor  $r$ , leads to a larger difference between the measured and the predicted values. Accordingly, it was recommended to amend Recommendation ITU-R P.530-17 to delete the upper limit of 2.5 on the  $r$  factor.

The input was approved and the upper limit of  $r=2.5$  will be deleted in the updated Recommendation ITU-R P.530-18 in due course. The data will be submitted to the databank of Study Group 3 meeting in 2022 as invited by WP-3M.

FIGURE 10

Fixed link RF heads of the measurement setup, (a) transmitter box for a 36 m link, (b) receiver box for direct 36 m link, (c) receiver box for side 36 m link, (d) transceiver Filtronic box for 200 m link, (e) block diagram of direct and side links



a) Transmitter



b) Receiver-direct



c) Receiver-side



d) Filtronic transceiver

FIGURE 11

Long-term rain attenuation measurement for direct 36 m link at K and E bands through dominant recorded rainy days between October 2020 and January 2021 (a) rain fall rate, (b) attenuation of K and E bands, (c) snow flakes and snow grains

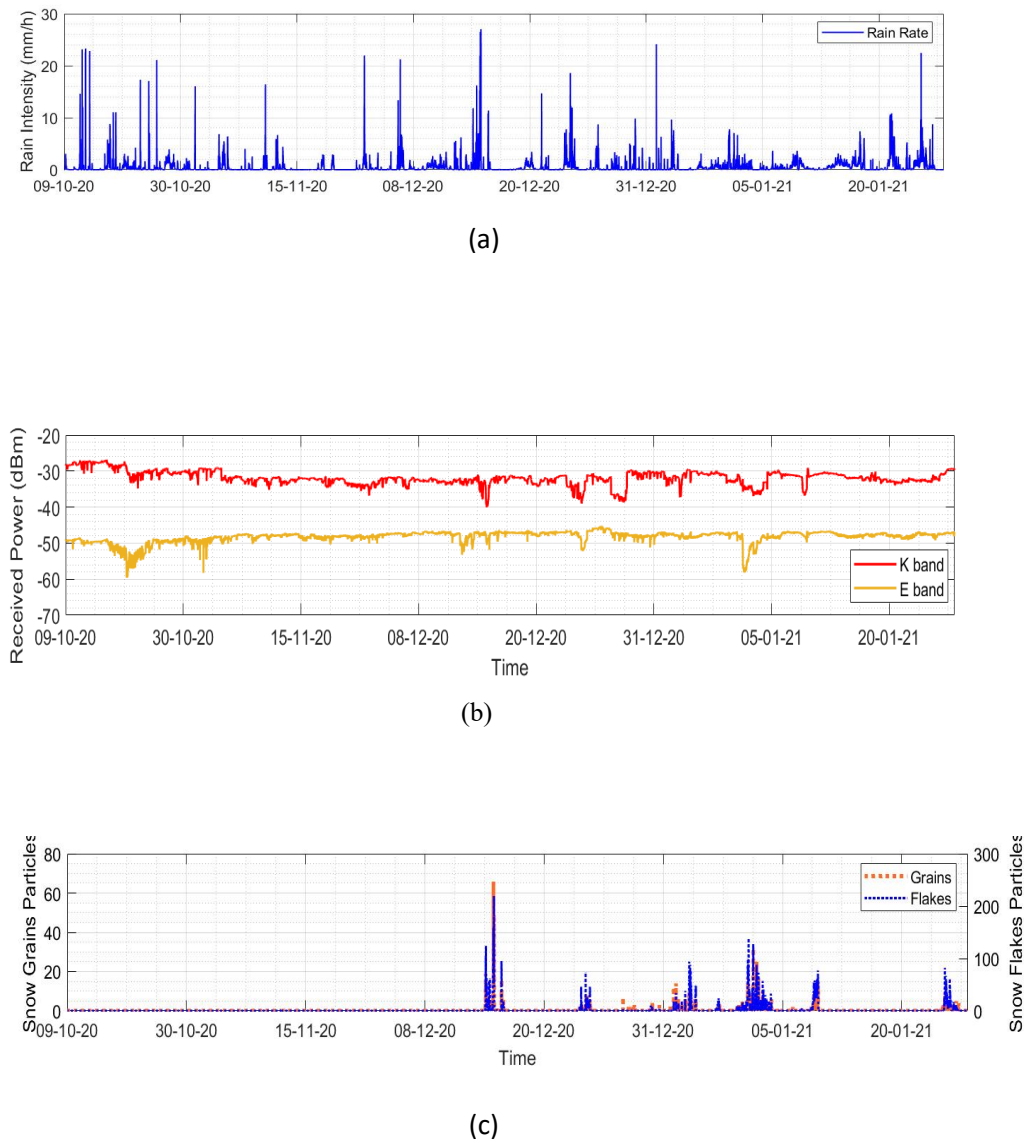
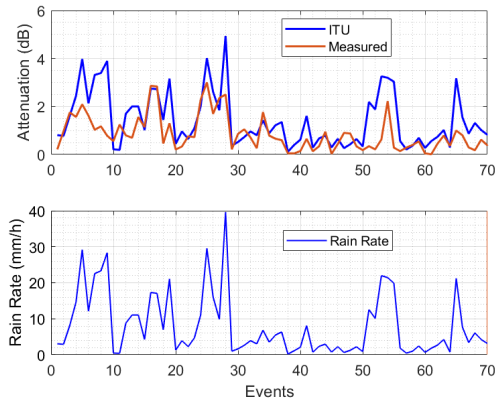
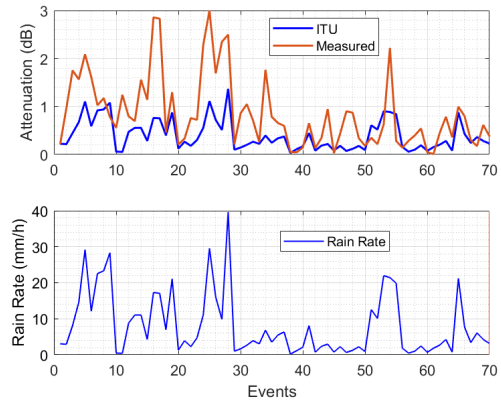


FIGURE 12

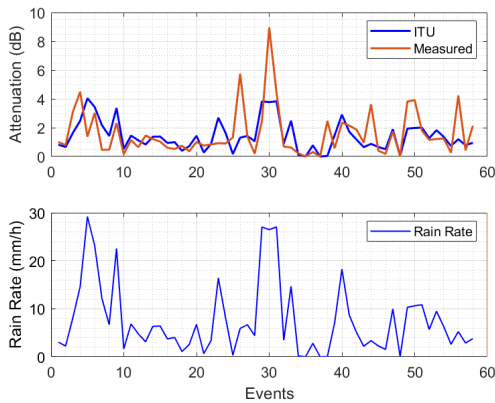
**Measured and ITU predicted rain attenuation for E band for the three links with and without using the maximum distance factor of 2.5**



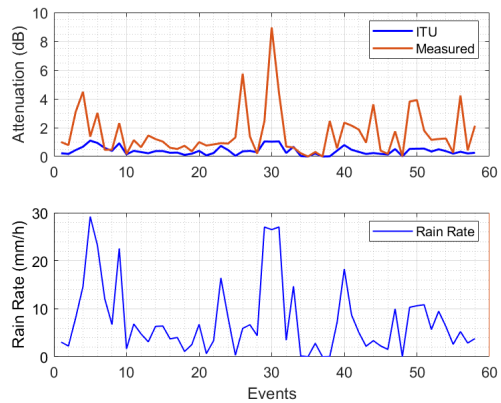
a) E band 36 m direct link: without distance factor restriction



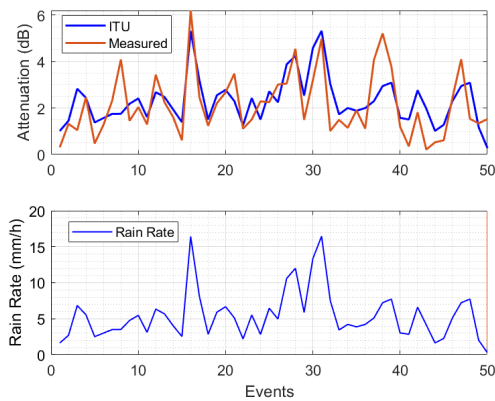
b) E band 36 m direct link: with distance factor restriction



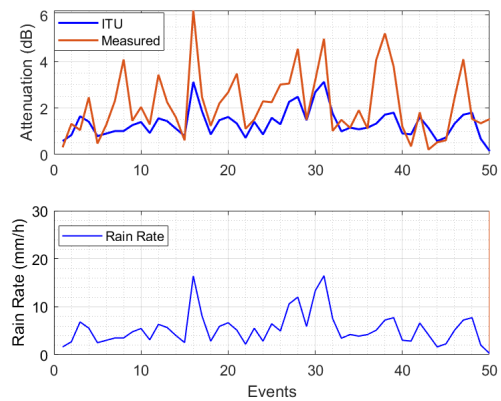
c) E band 36 m side link: without distance factor restriction



d) E band 36 m side link: with distance factor restriction



e) E band 200 m link: without distance factor restriction



f) E band 200 m link: with distance factor restriction

## 4. Submission of weather data to the Databank of SG3

In this document, the weather data collection device which consists of a high performance disdrometer, set up to study the impact of precipitation on fixed links for building-to-building transmission is described. The disdrometer shown in Figure 13 can provide accurate information on the type of rain, rain intensity, and the diameter of rain drop size distribution (DSD). Table 1 shows the main parameters of the PWS100 weather station.

The contribution submits the radio-meteorological data to DBSG-3, for Tables IV-1 on statistics of rain intensity, IV-5 on statistics of rain event duration, and IV-12 on statistics of rain drop size distribution.

FIGURE 13

**PWS100 present weather station installed for the study of rain statistics**



TABLE 4

**Main parameters of the PWS100 present weather station**

<b>Particle size</b>	0.1 to 30 mm
<b>Size accuracy</b>	±5% (for particles larger than 0.3 mm)
<b>Particle velocity</b>	0.16 to 30 m/s
<b>Velocity accuracy</b>	±5% (for particles larger than 0.3 mm)
<b>Types of precipitation detected</b>	Drizzle, freezing drizzle, rain, freezing rain, snow grains, snowflakes, ice pellets, hail, graupel
<b>Rain rate intensity range</b>	0 to 400 mm/h
<b>Rainfall resolution</b>	0.0001 mm
<b>Rain total accuracy</b>	Typically ±10%

The experimental datasets were submitted to the databank of the ITU, on statistics of rain intensity, on statistics of rain event duration, and on rain DSD statistics.

## Conclusions

Five inputs covering three different ITU Recommendations were submitted to the ITU SG3 with corresponding data sets to the databank where appropriate. This has resulted in the modification of two recommendations: ITU-R P. 1238 and ITU-R P. 530. An information document was also submitted confirming the validity of ITU-R P. 2108 for short links, typical of 5G radio networks. Weather data and clutter loss data were submitted to the databank of SG3. Further data sets will be submitted to the DBSG3 for short fixed links and for the measured indoor environments.

## References

ITU-R P. 1238-10 Propagation data and prediction methods for the planning of indoor radiocommunication systems and radio local area networks in the frequency range 300 MHz to 450 GHz

ITU-R P. 530-17 Propagation data and prediction methods required for the design of terrestrial line-of-sight systems

ITU-R P. 2108-0 Prediction of clutter loss