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Parameterization of the COST 2100 MIMO Channel Model in Indoor Scenarios

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***Abstract*—The COST 2100 MIMO channel model is the latest evolution of the geometry-based stochastic channel models developed by the COST actions. This paper provides a full parameterization of the COST 2100 channel model in four indoor scenarios based on channel measurements conducted in two different buildings. In addition to the parameter values, the meaning and extraction method of each parameter are explained.**

***Index Terms*—Channel modeling, channel measurements, COST 2100 MIMO channel model**

I. Introduction

MIMO is a key technology enabling reliable high data rate communications over the wireless channel, and it plays an essential role in numerous emerging standards such as LTE, and WiMAX. However, the performance of MIMO systems is fundamentally dependent on the characteristics of the radio channel in which the systems operate, meaning that they should be developed from the start to operate under realistic usage conditions. To this end, realistic and accurate channel models are a mandatory prerequisite.

Among many approaches, geometry-based stochastic channel models (GSCMs) have recently seen a lot of interest in MIMO channel modeling due to their inherent capability to model spatial and temporal characteristics of radio channels in a straightforward manner. Essentially, all GSCMs ground their operation on clusters that are randomly placed in simulation environments to act as physical scatterers, and the parameters (such as directions and delays) of each multipath component (MPC) are calculated based on the locations of the clusters, mobile station (MS) and base station (BS). Typically, clusters and BS are at fixed positions, and as the MS moves, the MPC parameters change smoothly and in a realistic manner as a function of time. An example of a generic GSCM is shown in Figure 1. Here the model includes a single bounce cluster, a pair of double bounce clusters and a local cluster around the MS. Examples of previous cluster-based GSCMs are the WINNER channel model [1], and COST 259 and COST 273 channel models [2], [3]. The COST 2100 channel model, which is considered in this paper, is the latest evolution of the GSCMs developed within the COST actions.

One of the essential features of the GSCMs is that different environments are characterized by changing the input parameters of the model, and basically an infinite number of environments can be simulated with the same modeling framework just by changing the parameter sets. Unfortunately, probably the most severe bottleneck in all the existing GSMCs has turned out to be exactly the parameterization of the different scenarios. Since channel sounding measurement campaigns are extremely laborious and expensive, no one can, in practice, measure all the possible scenarios. Furthermore, to derive the full set of parameters needed by a comprehensive GSCM based on the measurement data is a cumbersome task in itself. In order to take a step towards a more complete parameterization, this paper provides a full parameterization for the COST 2100 channel model in indoor scenarios based on four dynamic measurements conducted in two different buildings.

The paper is organized in the following way. Section II describes the measurements and data processing methodology. Section III introduces the parameters needed by the COST 2100 channel model along with example results from a reference measurement. Section IV concludes the work. Parameter values for all four measurements are provided in Appendix in the end of the paper.

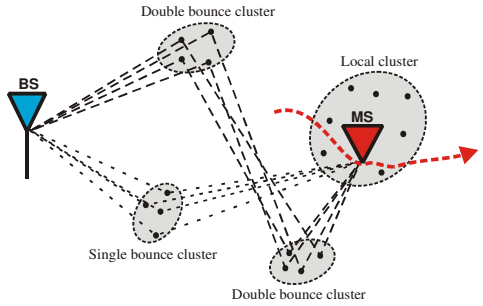

Fig. 1. Example of a GSCM. The black dots inside each cluster depict the individual MPCs.

II. Measurements and Data Processing

A. Measurement environments and measurement equipment

The analyzed measurements were done in the Computer Science (CS) building, and in the Department of Radio Science and Engineering (RS), in Aalto University School of Science and Technology by using a dual-link channel sounder [4]. The sounder consists of one transmitter (TX) and two receivers (RXs) and is capable of simultaneously measuring two dual-polarized links having the MIMO matrix sizes of 30 × 30 and 30 × 32.

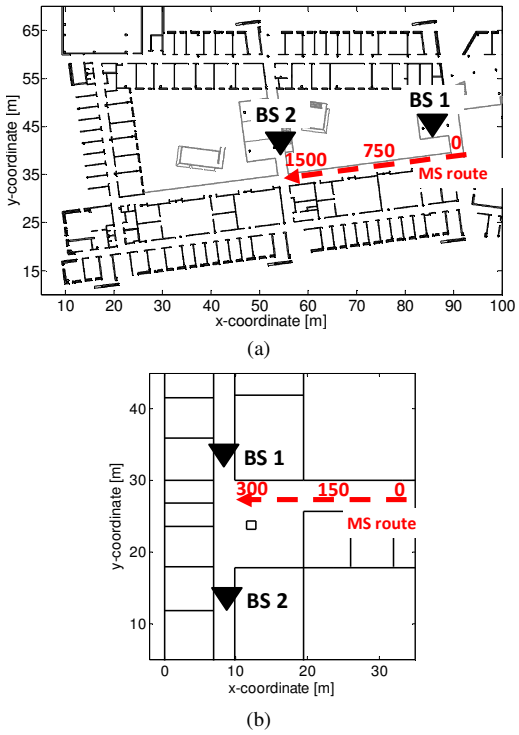

Fig. 2. Floor plan of the measurement environment with transmitter routes and receiver positions. (a) Indoor hall scenario in Computer Science building. (b) Office corridor scenario in Department of Radio Science and Engineering. Both buildings are located in Aalto University School of Science and Technology, Helsinki, Finland.

The first measurement was carried out in the CS building which is a three-storey office building with a large hall in the middle, as shown in Fig. 2(a). In the measurement, BS1 was located on a balcony on the second floor and BS2 on a bridge that connected the two sides of the building on the second floor. The MS was moving along a balcony on the hall side of the second floor. In the CS building measurement, there were line-of-sight (LOS) conditions throughout the measurement. The second measurement was carried out in the RS corridor. In this case, the MS was moving along a corridor towards a T-junction, and the two BSs were located on opposite sides of the perpendicular corridor seen from the MS, as shown in Fig. 2(b). In the RS building measurements, both links were in NLOS for the entire measurement. As the analyzed measurements include two MS routes measured with a dual-link sounder, altogether four different scenarios were measured and the total number of measurement samples (snapshots) is 3600.

B. *Cluster Extraction Methodology*

The cluster extraction methodology relies on the assumption that there exists a unique physical scattering object (or a group of objects in case of multiple bounce clusters) that can be identified in the measurement environment for each cluster. Since each MPC obtained from the measurement data by a parameter estimation algorithm includes the Direction-of-Departure (DoD) and -Arrival (DoA), and delay (τ), together with the map of the environment, they can be used to discuss the propagation paths and the scattering objects associated with the signals.

In this work, the parameter estimates of the propagation paths have been obtained by the Extended Kalman Filter (EKF) [5], which is a high-resolution parameter estimation and –tracking algorithm. Each MPC of the EKF parameter estimates includes the DoD, DoA, τ, and polarimetric path weight. Furthermore, each propagation path obtained by the EKF has a lifetime over a certain number of consecutive snapshots over the measurement routes.

In order to identify the relevant propagation mechanisms, i.e. the clusters, the EKF estimates of the DoD, DoA and τ were used as inputs for a measurement-based ray tracer (MBRT) [6]. The MBRT implements an algorithm that plots rays on top of a floor plan of the measurement environment according to the measured parameter estimates. It thus shows the physical propagation path of each MPC, enabling the clusters to be explicitly mapped to physical scatterers in the environment. In this work a cluster is defined as a group of MPCs originating via similar scattering processes, e.g. via a reflection from the same wall.

III. Channel Model Parameters

The parameters of the COST 2100 channel model can be roughly categorized into external parameters, that describe the system settings and environmental features, including for instance the centre frequency and bandwidth, and positions of the BS and MS, antenna heights, average rooftop height in the environment, cell radius, etc., and into stochastic parameters that characterize clusters. The stochastic parameters are further divided into three classes: 1) inter-cluster parameters, 2) intra-cluster parameters, and 3) cluster location parameters. The inter-cluster parameters describe the global cluster settings, e.g. the total number of cluster and their relationships with each other. The intra-cluster parameters, on the other hand, are necessary in order to describe how the MPCs are arranged within each cluster thus specifying the internal structure of the clusters. Cluster location parameters define how the clusters are located in the simulation coordinates.

Next, the definition and extraction method for each channel model parameter are described. For each parameter, example result is shown for the MS – BS1 link in the CS building measurement (called "reference scenario" hereinafter). The parameters values for the rest of the scenarios are listed in summary tables in the Appendix.

A. *Inter-cluster parameters*

The following inter-cluster parameters were extracted:

- Number of clusters
- Radii of the cluster visibility regions
- Cluster decay factor
- Cluster selection parameter
- LOS power factor

In the COST 2100 channel model, the number of clusters is implicitly determined based on the concept of visibility regions (VRs): each cluster is assigned with a VR and the corresponding cluster is active only when the MS is inside the VR. The total number of active clusters is thus specified by the number of VRs inside which the MS is at each time instant. The concept of VRs is in that sense intelligent that, in addition to the instantaneous number of active clusters, the

dynamic behavior, i.e. the appearance and disappearance, of the clusters is simulated in a realistic manner.

Owing to the visibility region concept introduced by the COST 2100 channel model, values for two parameters need to be adjusted based on measurement data in order to simulate the number of clusters and its evolution in a realistic manner: 1) Total number of active clusters, and 2) the lifetimes of each cluster, i.e. the radii of the VRs.

Fig. 3(a) shows the number of active clusters as a function of snapshot in the reference scenario. The number of active clusters varies between 2 and 6, the mean and the standard deviation being 3.69 and 0.78, respectively. The results were very similar also in other scenarios. The radii of the VRs were calculated simply by translating the lifetimes of the clusters to meters and dividing the result by two. Since the lifetime of the cluster is equivalent to the diameter of the VR, it has to be divided by two to get the radius. The CDF of the VR radii is shown in Fig. 3(b). The mean and standard deviation of the VR radii are 2.72 m and 2.28 m.

The COST 2100 includes the option to distinguish between the single- (SBCs) and multiple bounce clusters (MBCs). This improves the accuracy of the model, since the different cluster types can be assigned with different parameters. The ratio of SBCs and MBCs is denoted by the so called cluster selection factor K_{sel}:

$$K_{\mathrm{sel}} = \frac{N_{\mathrm{SBC}}}{N_{\mathrm{SBC}} + N_{\mathrm{MBC}}}, \tag{1}$$

where N_{SBC} and N_{MBC} are the number of SBCs and MBCs. Thus, $K_{\mathrm{sel}} = 1$ means that all clusters are SBCs and $K_{\mathrm{sel}} = 0$ that all clusters are MBCs.

Fig. 3(c) shows the cluster selection parameter K_{sel} as a function of snapshot in the reference measurement. Values for the K_{sel} are in the range between 0.3 and 1, and the mean and standard deviation are 0.70 and 0.19. That is, on average 70 % of the clusters are SBCs. Fig. 3(d) shows the power carried by the SBCs and MBCs in [%] of total power. It can be seen that the SBCs are significantly stronger than the MBCs in this scenario. It is assumed that in the RS building measurements all the clusters are MBCs, i.e. $K_{\mathrm{sel}} = 0$ in both links. Owing to the fact that is unlikely that in complex indoor environments with NLOS conditions the waves are able to reach the receiver by one interaction, it is recommended that the K_{sel} is always set to zero in indoor NLOS scenarios.

In the COST 2100 channel model one of the most fundamental properties that significantly affects the modeling results is to accurately adjust the power composition between different clusters. This is determined based on the LOS power factor K_{LOS}, which is the power of the first arriving MPC compared to the power of all other components, and based on the cluster decay factor k_τ, which settles the power of the clusters as a function of delay. The LOS power factor K_{LOS} is defined as the ratio of the power of the LOS component (or the first arriving MPC) and the power of all other MPCs, as

$$K_{\mathrm{LOS}} = \frac{P_{\mathrm{LOS}}}{P_{\mathrm{tot}} - P_{\mathrm{LOS}}}, \tag{2}$$

where P_{LOS} is the power of the LOS component and P_{tot} is the total power. The unit of K_{LOS} is [db]; 0 dB means that the LOS component represent half of the total power. Fig. 3(e) shows the LOS power factor in the reference measurement. It can be seen that K_{LOS} fluctuates generally between -5 dB and 5 dB. The mean and standard deviation of K_{LOS} are 0.37 and 2.77, respectively.

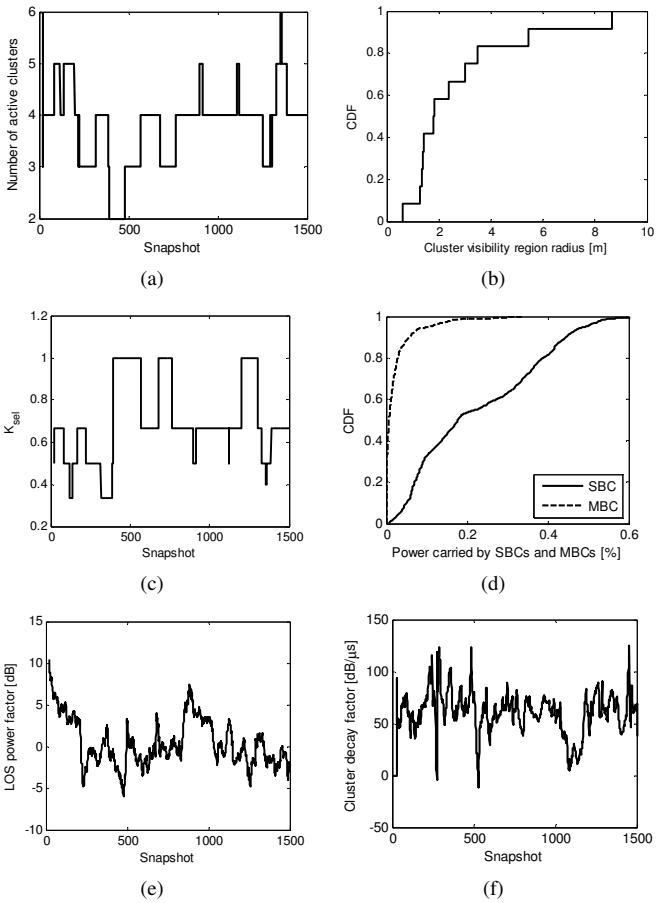

Fig. 3. (a) Total number of active clusters as a function of the MS location. (b) CDF of the visibility region radius. (a) Ratio of single and multiple bounce clusters. (b) Power carried by SBCs and MBCs. (e) LOS power factor. (f) Cluster decay factor. All parameters have been extracted from the reference measurement.

The power carried by each cluster is a function of the delay; basically, the longer the delay, the weaker the cluster power is. In the COST 2100 channel model, the power of cluster m P_m is modeled as a function of delay as

$$P_m = P_0 e^{-k_\tau(\tau_m - \tau_0)}, \tag{3}$$

where P_0 is the power of the LOS component, k_τ is the cluster decay factor, τ_m is the delay of the m-th cluster, and τ_0 is the delay of the LOS component. That is, the attenuation of the clusters is always determined with respect to the LOS path (or to the first arriving MPC). Cluster decay factor k_τ describes how rapidly the power of the clusters decays as a function of the propagation delay. The unit of k_τ is [dB/μs]. Cluster decay factor is plotted for the reference measurement as a function of snapshot in Fig. 3(f). Typically, the values for k_τ are between 30 and 80 [dB/μs], the mean value being 54 [dB/μs].

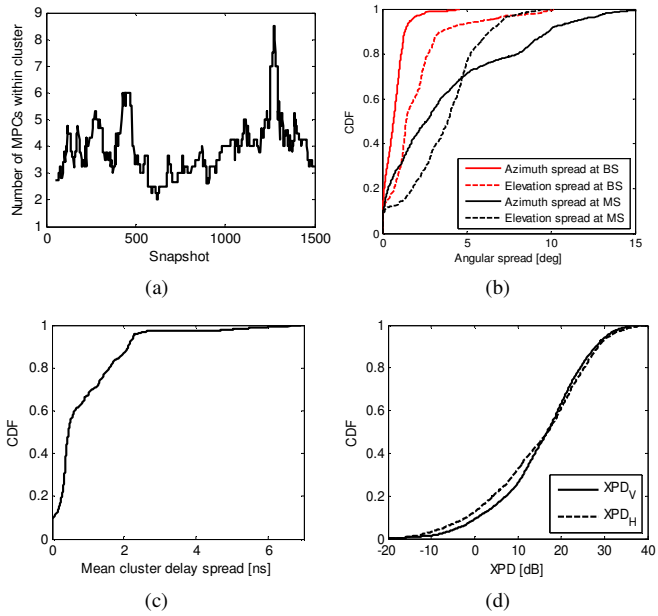

Fig. 4. (a) Number of MPCs within clusters. (b) Cluster angular spread. (c) Cluster delay spread. (d) Cross-polarization discrimination. All parameters have been extracted from the reference measurement.

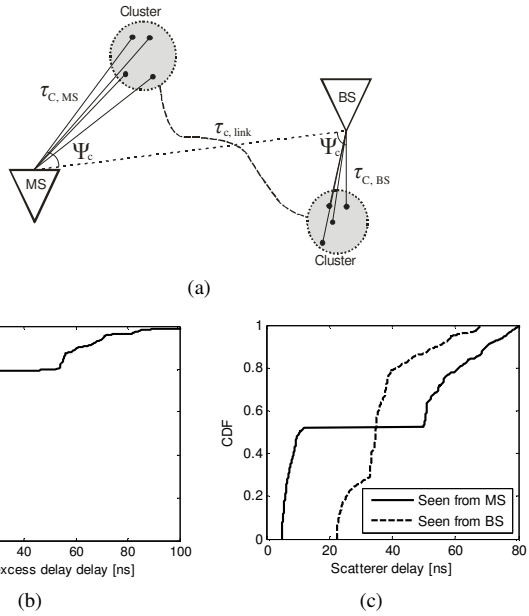

Fig. 5. (a) Parameters defining the locations of the clusters. CDFs of the (b) link excess delay and (c) scatterer delay. All parameters have been extracted from the reference measurement.

B. *Intra-Cluster Parameters*

The following intra-cluster parameters were extracted:

- Number of MPCs within clusters
- Cluster angular and delay spreads
- Cross-polarization discrimination

Fig. 4(a) shows the number of MPCs within clusters as a function of snapshot in the reference scenario. It can be seen that the number of MPCs within clusters is rarely more than 5, which is a significantly lower value than what has been previously used in the COST 273 channel model.

The cluster angular spread (*AS*) and delay spread (*DS*) are calculated for each cluster as

$$AS = \sqrt{\frac{\sum_i^N P_i(\varphi_i - \bar{\varphi})^2}{\sum_i^N P_i}}, DS = \sqrt{\frac{\sum_i^N P_i(\tau_i - \bar{\tau})^2}{\sum_i^N P_i}} \quad (4)$$

where φ_i is the DoD or DoA of the i-th MPC of the cluster, $\bar{\varphi}$ is the mean DoD or DoA of the cluster, and τ_i the delay of the i-th MPC and $\bar{\tau}$ is the mean delay of the cluster. N is the total number of MPCs within the cluster and P_i is the power of the i-th MPC. Fig. 4(b) shows the CDFs of the *AS*. It can be concluded that the *AS* is typically somewhat larger on the MS side than on the BS side. However, even on the MS side the *AS* rarely gets values of more than 5 degrees. In some cases, the *AS* is zero which means that at that those locations the cluster included only one MPC. No noticeable differences were observed between the *AS* in azimuth and elevation planes. As was the case in the *AS*, also the *DS* gets rather small values in this scenario. Based on Fig. 4(c) it can be concluded that the *DS* is typically between 0 ns and 2 ns.

The cross-polarization discrimination (*XPD*) is a parameter which indicates how large proportion of the signal transmitted with a certain polarization shifts into another polarization as it propagates through the channel. The *XPD* is calculated for each MPC for signals transmitted with V- and H-polarization as

$$XPD_{\mathrm{V}} = \frac{P_{\mathrm{VV}}}{P_{\mathrm{VH}}},\ XPD_{\mathrm{H}} = \frac{P_{\mathrm{HH}}}{P_{\mathrm{HV}}} \quad (5)$$

where P_{IJ} is the power of the wave which was transmitted at the *I*– and received at the *J*–polarization. As can be seen in Fig. 4(d), the XPD_{V} and XPD_{H} are very close to each other in this environment, the mean and standard deviation being approximately 15 dB and 10 dB in both cases.

C. *Cluster Location Parameters*

The cluster location parameters define how the clusters are distributed in the simulation coordinates. Three location-dependent parameters are defined based on the location of the scatterers in the measurements: 1) Link excess delay $\tau_{\mathrm{c,link}}$, 2) scatterer delay $\tau_{\mathrm{C,MS/BS}}$ and 3) scatterer angle Ψ_{c}. Link excess delay $\tau_{\mathrm{c,link}}$ denotes the delay time of intermediate propagation between the first and last scattering point of the MPC. Thus, for the SBCs $\tau_{\mathrm{c,link}}$ is in principle zero. The scatterer delay $\tau_{\mathrm{C,MS/BS}}$, on the other hand, is the delay time between MS or BS and the first or last scattering point. Hence, the total delay associated with the cluster can be expressed as

$$\tau_{\mathrm{C}} = \tau_{\mathrm{C,BS}} + \tau_{\mathrm{C,link}} + \tau_{\mathrm{C,MS}}. \quad (6)$$

Scatterer angle Ψ_{c} is the angle between the line connecting the MS and BS and the line connecting the MS or BS and the first of last scattering point. Fig. 5(a) clarifies what is meant by each cluster location parameter.

In order to extract the cluster location parameters from the measurement data, the first interaction point after the TX and the last interaction point before the RX have to be determined. This is done by calculating the intersection point between the ray launched from the TX or RX and the physical object that the launched ray hits first. The rays are launched in the MBRT from the TX or RX according to the direction of the DoD or

DoA of each MPC. Figs. 5(b) and (c) show the CDFs of the links excess delaya and scatterer delay, respectively. It can be seen that in about 70 % of the cases, $\tau_{\mathrm{c,link}}$ is less than 10 ns. These small nonzero values correspond to $\tau_{\mathrm{c,link}}$ of the SBCs; even for the SBCs $\tau_{\mathrm{c,link}}$ is never exactly zero due to practical inaccuracies in the measurements. However, it can be seen that for the MBCs $\tau_{\mathrm{c,link}}$ is typically between 20 ns and 80 ns. The scatterer delay $\tau_{\mathrm{C,MS/BS}}$ gets values roughly between 10 ns and 80 ns.

IV. CONCLUSIONS

This paper presents the parameterization of the COST 2100 MIMO channel model in indoor scenarios. A full set of parameter values have been extracted based on four dynamic double directional channel sounding measurements conducted in two different buildings, including LOS hall and NLOS office environments.

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APPENDIX

VALUES FOR THE EXTRACTED CHANNEL MODEL PARAMETERS

Table 1. Parameter values for the inter-cluster parameters.

Measurement	CS, BS1	CS, BS2	RS, BS1	RS, BS2
Number of clusters N_{C}				
$\mu_{N_{\mathrm{C}}}$	3.69	3.90	4.27	3.72
$\sigma_{N_{\mathrm{C}}}$	0.78	1.41	0.67	0.80
Radius of the visibility region VR [m]				
μ_{VR}	2.77	2.76	3.77	1.79
σ_{VR}	2.44	2.23	2.22	2.47
Cluster selection factor K_{sel}				
$\mu_{K_{\mathrm{sel}}}$	0.70	0.62	0	0
$\sigma_{K_{\mathrm{sel}}}$	0.19	0.15	0	0
LOS power factor KLOS [dB]				
μ_{K}	0.37	-0.75	-9.721	-
σ_{K}	2.77	2.77	7.39	-
Cluster decay factor k_τ [dB/μs]				
μ_{k_τ}	54.23	31.84	5.87	15.96
σ_{k_τ}	25.74	23.00	8.75	63.94

[1] The LOS power factor was calculated in locations where the O-LOS component existed.

Table 2. Parameter values for the intra-cluster parameters.

Measurement	CS, BS1	CS, BS2	RS, BS1	RS, BS2
N.o. MPCs in cluster N_{MPC}				
$\mu_{N_{\mathrm{MPC}}}$	3.91	4.47	3.66	2.76
$\sigma_{N_{\mathrm{MPC}}}$	1.01	1.35	0.56	0.67
Angular spread *AS* [deg]				
$\mu_{\varphi_{\mathrm{BS}}}$	0.71	1.68	3.93	1.13
$\sigma_{\varphi_{\mathrm{BS}}}$	0.59	1.51	3.93	0.77
$\mu_{\theta_{\mathrm{BS}}}$	1.95	1.41	3.74	0.54
$\sigma_{\theta_{\mathrm{BS}}}$	1.80	1.11	3.99	0.44
$\mu_{\varphi_{\mathrm{MS}}}$	3.94	3.84	6.6	1.42
$\sigma_{\varphi_{\mathrm{MS}}}$	3.91	2.07	3.00	1.03
$\mu_{\theta_{\mathrm{MS}}}$	3.73	3.97	1.48	0.91
$\sigma_{\theta_{\mathrm{MS}}}$	2.11	2.32	0.93	0.87
Delay spread *DS* [ns]				
μ_τ	1.07	1.65	4.48	1.98
σ_τ	0.93	1.67	1.52	1.61
Cluster K-factor K_{c} [dB]				
min	0.40	0.28	0.36	0.39
max	∞	∞	∞	∞
$\mathrm{XPD_V}$ / $\mathrm{XPD_H}$ [dB]				
μ_{XPD}	15.59 / 14.89	12.73 / 13.57	9.55 / 11.35	13.06 / 11.49
σ_{XPD}	10.39 / 11.80	10.86 / 9.88	9.48 / 8.73	7.96 / 9.11

Table 3. Parameter values for the cluster location parameters

Measurement	CS, BS1	CS, BS2	RS, BS1	RS, BS2
Link excess delay $\tau_{\mathrm{c,link}}$ [ns]				
$\mu_{\tau_{\mathrm{c,link}}}$	34.01	83.17	45.35	55.41
$\sigma_{\tau_{c,link}}$	64.43	71.70	29.31	27.67
Cluster delay $\tau_{\mathrm{C,MS/BS}}$ [ns]				
$\mu_{r_c,\mathrm{BS}}$	36.24	89.77	49.90	18.01
$\sigma_{r_c,\mathrm{BS}}$	11.00	55.31	29.96	12.42
$\mu_{r_c,\mathrm{MS}}$	32.79	71.32	17.94	22.01
$\sigma_{r_c,\mathrm{MS}}$	27.67	63.03	18.51	18.48
Cluster angle Ψ_{c} [deg]				
$\mu_{\Psi_{\mathrm{c}},\mathrm{BS}}$	54.61	47.82	49.88	43.16
$\sigma_{\Psi_{\mathrm{c}},\mathrm{BS}}$	55.67	62.70	38.52	39.14
$\mu_{\Psi_{\mathrm{c}},\mathrm{MS}}$	58.41	29.94	5.67	5.54
$\sigma_{\Psi_{\mathrm{c}},\mathrm{MS}}$	44.43	36.30	3.72	6.75