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Comparison of Delay and Angular Spreads between Channel Measurements and the COST2100 Channel Model

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***Abstract*—The COST2100 channel model is a reference channel model which provides dynamic multiple-input multiple-output channel responses for radio system simulations. In this paper, channels created by the COST2100 model were compared to channel measurements in order to understand behaviours of the model. Model parameters of the COST2100 model were derived by dynamic double-directional channel measurements with which the channel realizations from the COST2100 model were compared. Delay and angular spreads were used as a simple but important metric for the comparison. Despite a fundamental difference that the COST2100 model is a geometry-based stochastic model while the channel measurements are obtained in deterministic environments, the comparison revealed an acceptable level of agreement for practical channel simulations.**

I. INTRODUCTION

Reference channel models are important tools for the design, development, and standardization of radio systems. Many of such channel models, such as the COST273 [1], the COST2100 [2], and the WINNER II [3] channel models, are developed based on a concept of geometry-based stochastic channel model because of its flexibility in multiple-input multiple-output (MIMO) simulations and scalability for multi-link extension. The geometry-based stochastic channel model considers a map with many clusters placed randomly together with a base station (BS) and mobile station (MS) to generate radio channel responses. Angles, delays, and power of multipaths of each cluster are determined by locations of clusters, BS, and MS on the map. The model is different from deterministic ray-tracing in the sense that large-scale cluster properties, such as cluster locations, are determined in a stochastic way using empirical distributions characterized by radio channel measurements. Dynamic and multi-link channel simulations can be performed by dropping multiple BSs and MSs, and by moving MSs on the map. Despite extensive development of the reference channel models, there has been only a few reports discussing the validation of those models [4], [5]. This is partly because there is no single methodology and metric for ”sufficient” channel model validation. Appropriate methodology and the metric can change depending on the usage of the channel model, and therefore, it is hard to make a decisive conclusion on the general applicability, accuracy, and suitability of the channel model. Another challenge for meaningful validation of channel models is a selection of an appropriate reference based on which the channel model is evaluated. In many cases the reference is measurement data based on which channel model parameters are derived. The nature of channel model and corresponding references must be consistent to each other as much as possible to make a sound comparison.

Looking at a particular metric to compare channel model outputs and measurements, channel capacity and eigenvalue-related measures were used in many papers. For example, Kyösti *et al.* [4] made a comparison between the WINNER I channel model with channel measurements by means of channel capacity, Demmel condition number, and channel diversity. Zhang *et al.* [5] also used distribution of channel capacity and eigenvalue realizations to compare their measurements with their reference channel model. Czink [6], [7] made a thorough analysis to validate his random cluster model, where a new metric, the environmental characterization metric (ECM), was proposed. The ECM is a second-order moment of spatio-temporal power spectrum of radio channels.

Since it is an important task to validate the COST2100 channel model, this paper compares the COST2100 channel model output against real-world measured channel data. As fundamental level of comparison metrics, angular and delay spreads were chosen since those properties govern many other properties of the system metric, *e.g.,* eigenvalue and capacity distribution. The results revealed an acceptable level of agreement for practical channel simulations.

II. COMPARISON BETWEEN THE COST2100 CHANNEL MODEL AND MEASUREMENTS

A. Methodologies

The flow of the comparison is shown in Fig. 1. The COST2100 channel model was based on the previously developed COST273 model [1], and further refined and implemented by Liu *et al.* [8]. On the other hand, parameters of the COST2100 channel model were derived from double-directional channel sounding and propagation modeling in the WILATI+ project [9]. The propagation modeling includes

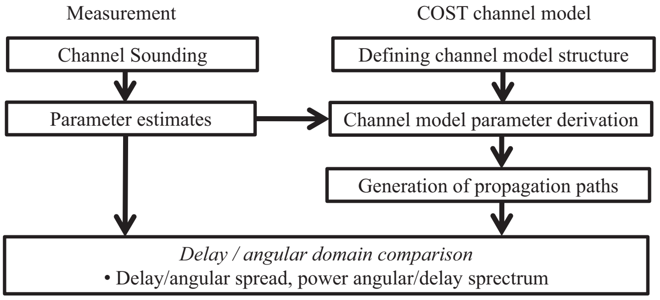
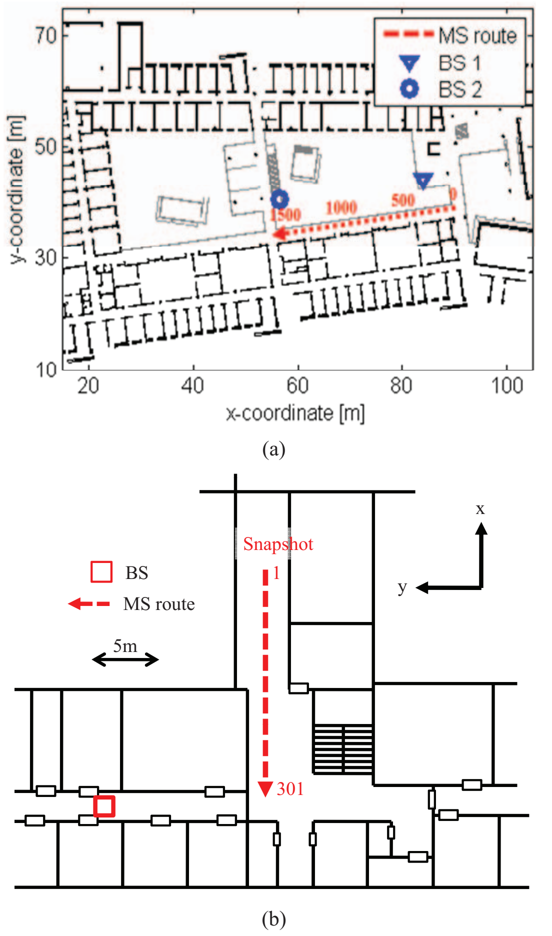


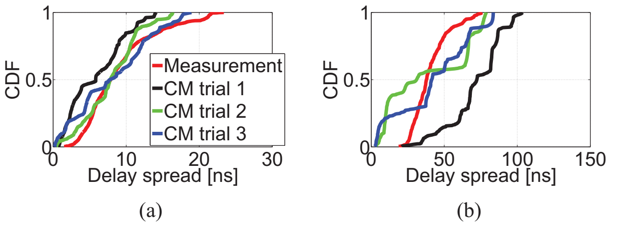
Fig. 1. Flow chart of the comparison of the COST2100 channel model against channel measurements.



(a)

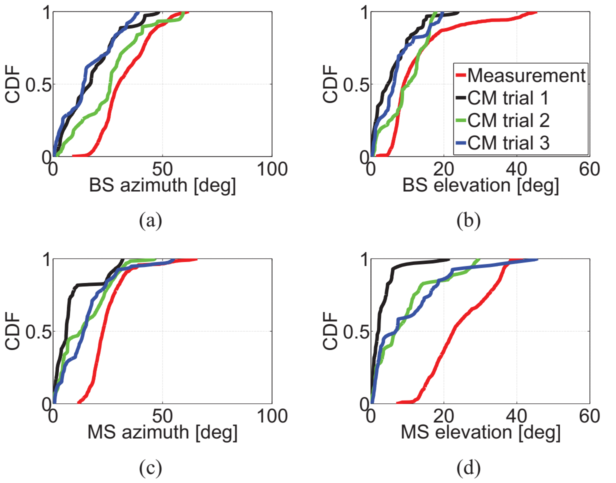
(b)

Fig. 2. Maps of the measurement environments: (a) large hall and (b) corridor environments.



(a) (b)

Fig. 3. Comparison of delay spreads between measurements and the COST2100 model: (a) LOS hall and (b) NLOS corridor scenarios.



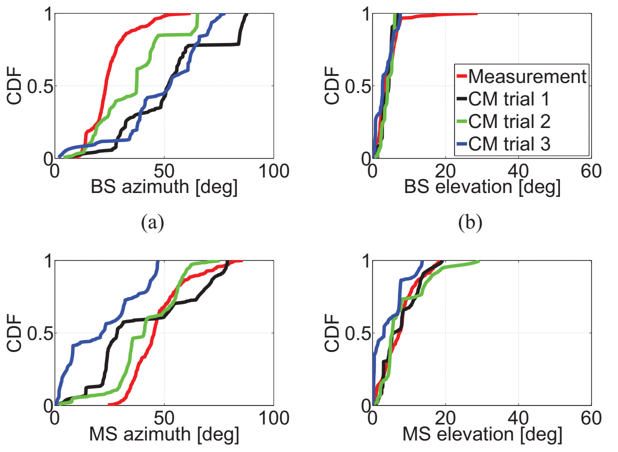
(a) (b)

(c) (d)

Fig. 4. Comparison of azimuth and elevation angular spreads between measurements and the COST2100 model in the hall scenario: (a) BS azimuth, (b) BS elevation, (c) MS azimuth, and (d) MS elevation.

propagation path parameter estimates and identification of clusters using a geometrical map. Readers are directed to the references for the details of channel model structure, model parameter derivation, and channel sounding. The comparison was performed using discrete propagation paths from measurements and the channel model (which will be called "channel simulation" hereinafter). The channel simulation was made with the same geometrical setting of BS and MS locations as corresponding measurements. Since the channel model parameters were derived from estimated propagation paths of channel measurements, properties of resulting propagation paths from the channel simulation should agree with those of the measurements. Among many metrics for the comparison, angular and delay spread was chosen since 1) they can be derived without considering antennas, and 2) they are fundamental and affecting other metrics such as eigenvalue and channel capacity distributions.

A set of simplification was made for the comparison. First, only vertical co-polarized path weights were considered, since a channel model "add-on" for multi-polarization simulation is still under development. It means co-polarized horizontal polarizations and cross-polarization components were not taken into account. Second, local clusters, which are placed around the BS and MS and revealing uniform angular power spectrum over azimuth angles in indoor scenarios (cf. pp. 369 of [1]), were inactivated in the channel simulation because it was not possible to detect them in the measurements. Finally, only specular propagation paths were taken into account for the comparison and dense multipath components were not considered. In the reference routes described in the next subsection, the specular components contained 70% and 10% of the total power on average for the line-of-sight (LOS) and non-line-of-sight (NLOS) scenarios, respectively. Rest of the power was classified as dense multipath components. Comparison of channel simulations and measurement data for the dense



(a) (b)

(c) (d)

Fig. 5. Comparison of azimuth and elevation angular spreads between measurements and the COST2100 model in the corridor: (a) BS azimuth, (b) BS elevation, (c) MS azimuth, and (d) MS elevation.

multipaths is beyond the scope of this paper although it is very important particularly in NLOS scenarios. The following explains the measurement scenarios under consideration.

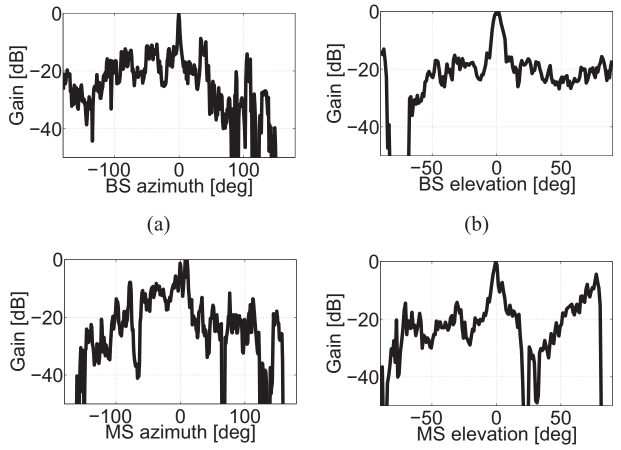
B. Measurement Scenarios

The tested scenarios were an indoor hall environment with LOS components denoted as the measurement ”CS, BS1”, and an NLOS indoor corridor scenario called ”RS, BS1” in [9]. The floor plans of the measurement scenarios are shown in Fig. 2. Each measurement consists of a fixed transmit BS location and an MS route along a line in a terrace and in a corridor as shown in Fig. 2. The first 1400 and 300 MS locations, which correspond to 28 and 20 m of the length of the MS routes, were considered for the comparison in the LOS hall and NLOS corridor scenarios, leading to channel samples at every 20 and 67 mm of the MS movement on average, respectively. Channel model parameters of those scenarios are given in the Appendix of [9]. For consistency of the definition with the COST2100 channel model, angles and delays of the measurements were normalized by those of a *geometrical* LOS (not the measured LOS propagation paths) at each MS location.

III. RESULTS AND DISCUSSIONS

A. Delay Spread

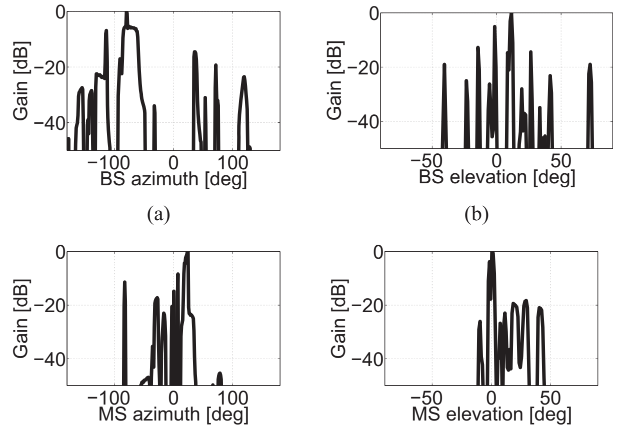
Cumulative distribution functions (CDFs) of the delay spread were compared between measurements and three runs of channel simulation outputs as shown in Fig. 3. The mean value of the delay spread was 9.0 ns in the measurement, while it was 5.9, 7.9, and 8.1 ns in the channel simulation output for the LOS scenario. In the NLOS case, the delay spread was 71.8, 39.5, and 42.4 ns for the three runs of the channel simulation and that of the measurement was 40.4 ns. The first trial of the channel simulation overestimated the delay spread, while it was almost in the same range in other cases. The channel simulation output revealed accuracy of delay spread prediction within the relative error of -35 to $+80$ %.



(a) (b)

(c) (d)

Fig. 6. Large-scale averaged power angular spectrum of the *measurement* in the hall scenario: (a) azimuth on BS, (b) elevation on BS, (c) azimuth on MS, and (d) elevation on MS; 0° corresponds to angles of geometrical line-of-sight between the BS and MS. LOS components are excluded in these plots in order to highlight structure of multipaths.



(a) (b)

(c) (d)

Fig. 7. Large-scale averaged power angular spectrum of the *COST2100 channel model output* for the hall scenario: (a) azimuth on BS, (b) elevation on BS, (c) azimuth on MS, and (d) elevation on MS; 0° corresponds to angles of geometrical line-of-sight between the BS and MS. LOS components are excluded in these plots in order to highlight structure of multipaths.

Looking at the CDF curve, it is possible to make two observations: 1) the curves from the channel simulation are often not as smooth as those of measurements, and 2) the delay spreads from different runs of the channel simulation vary significantly. The former is because of the death and birth of clusters along the MS route where the large-scale property of the channel changes significantly. Drastic change of large-scale property tends to occur when the number of clusters is small and also when the cluster death and birth happen suddenly in the channel simulation. The variation of the delay spread over different channel simulation runs is inevitable because of a small number of large-scale independent samples during each simulation run.

TABLE I
COMPARISON OF MEAN ANGULAR SPREADS BETWEEN CHANNEL MEASUREMENTS AND SIMULATIONS. THE VALUES IN PARENTHESES SHOW DIFFERENCE RELATIVE TO THE MEASUREMENT.

LOS hall

	Az. BS	El. BS	Az. MS	El. MS
Model run 1	17.5° (−47 %)	5.9° (−53 %)	8.6° (−65 %)	2.9° (−88 %)
Model run 2	25.7° (−22 %)	9.6° (−24 %)	14.2° (−42 %)	9.0° (−63 %)
Model run 3	15.8° (−52 %)	7.2° (−43 %)	15.2° (−38 %)	9.8° (−60 %)
Measurement	32.9°	12.6°	24.6°	24.3°

NLOS corridor

	Az. BS	El. BS	Az. MS	El. MS
Model run 1	52.4° (+111 %)	4.0° (−3 %)	40.1° (−15 %)	7.5° (+3 %)
Model run 2	35.6° (+43 %)	4.2° (0 %)	41.4° (−12 %)	7.9° (+9 %)
Model run 3	48.7° (+96 %)	3.3° (−21 %)	21.6° (−54 %)	4.3° (−41 %)
Measurement	24.8°	4.2°	47.2°	7.3°

B. Angular Spread

Comparison of azimuth angular spreads for channel simulations and measurements are shown in Figs. 4 and 5 for the LOS hall and NLOS corridor scenarios, respectively. Mean spread values are summarized in Table I. Relative error of the simulation against measurement is also shown. The simulation underestimated the angular spread compared to measurements in the LOS hall scenario. The most visible underestimation appeared in the elevation spread on the MS side, while the results from the NLOS corridor scenario revealed both over and underestimation of azimuth spread values. Elevation spread agreed well in this scenario. The range of difference between simulations and measurements was -88 to -22 % in the LOS hall and -54 to $+111$ % in the NLOS corridor scenarios.

C. Discussions

In order to analyze the reason for the differences between the channel simulations and the measurements, large-scale averaged power angular spectrum (LSA-PAS) is compared for the LOS hall scenario as shown in Figs. 6 and 7. It must be noted that the LSA-PAS does *not* include the LOS for better exposition of the contribution of multipath components. It is clearly seen in the figures that the spectrum is more peaky and sparse in the simulations than in the measurements. The large elevation spread on the MS side is attributed to the strong response of high-elevated paths as shown in Fig. 6(d), while that response is not realized in the corresponding simulation, Fig. 7(d). This explains the reason for the underestimation of angular spreads. It is also worth mentioning that angles giving a peak of the spectrum differ between the measurements and the simulations.

The differences in the LSA-PAS can be explained by two reasons. The first reason is lack of explicit mechanism in the COST2100 channel model to relate cluster angles to power information; the COST2100 model determines cluster power by their delay information only. The angular dependency of the power, represented by the LSA-PAS, is considered only in determining cluster angles and not in cluster power. Thus the COST2100 model has less capability to maintain the measured global angular spread compared to the WINNER II channel model which utilizes the LSA-PAS to determine both cluster angles and power. The second reason is a difference of nature in the channel simulations and measurements; simulated channels are generated from a stochastic channel model while measurements are purely deterministic. Given the limited number of cluster samples available both in channel measurements and simulations, it is not possible to obtain perfect agreement between them even if a channel model is perfect. Our comparison is still meaningful in understanding the behaviour of the channel model under practical simulation conditions where only a limited samples of clusters are available.

IV. CONCLUSION

The comparison of channels from the COST2100 model and measurements revealed an acceptable level of agreement in terms of the angular and delay spreads for practical channel simulations. Although large discrepancy between channel simulations and models were sometimes observed because of stochastic behaviours of the channel model, the COST2100 channel model is a reliable tool for realistic and dynamic MIMO channel simulations.

ACKNOWLEDGMENT

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