Quasi-deterministic channel model for millimeter-wave indoor entrance hall access links

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Abstract: The IEEE 802.11ay channel models have been developed based on the quasi-deterministic (Q-D) channel modeling that considers environment specific property of millimeter-wave (mm-wave) propagation by representing multi-path channels as superposition of deterministic (called D-ray) and random clusters (called R-ray). Based on the Q-D model, this letter presented the inter-cluster parameters of the random clusters which were obtained from the double-directional channel measurement in an indoor entrance hall environment. Comparison between the parameters obtained in this study and those of the existing IEEE 802.11ay/MiWEBA model showed that both are reasonable values inferred from each corresponding environment.

Keywords: millimeter-wave, Q-D channel model, random ray, entrance hall, model parameter

Classification: Antennas and Propagation

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1 Introduction

As an emergence of new applications such as ultra-high definition (4K/8K) video streaming and virtual/augmented reality (VR/AR) technologies, a significant increase in data transmission throughput of wireless LANs is currently required. The IEEE 802.11ay which can support up to 30 Gbps throughput, a new standard at millimeter-wave (mm-wave) bands has attracted attention. In high frequency bands such as mm-waves, specular reflection should become a dominant propagation mechanism because the dimension of the scatterer is sufficiently large comparing with its wavelength. This makes it possible to predict approximate propagation characteristics using geometrical optics method, e.g., ray tracing. However, in the real environment, there exist several multi-path components that have a large power contribution but are difficult to predict by ray tracing.

The design and development of a wireless communication system requires a channel model that accurately represents radio propagation characteristics. The quasi-deterministic (Q-D) channel model approach [1] has been adopted in IEEE 802.11ay [2] to more accurately represent the inherent propagation characteristics of mm-waves. It is a cluster-based model where the deterministic and random clusters are separately modeled. The deterministic cluster (called D-ray) is a cluster that always exists regardless of the transmitter (Tx) and receiver (Rx) positions in the environment. That includes a direct wave, wall reflected waves, ground reflected waves, etc., which can be generated deterministically by ray tracing. On the other hand, the random cluster (called R-ray) is a cluster generated by scattering or reflection from random objects such as small or irregular shaped scatterers such as furniture and pillars, and this is generated stochastically from statistics obtained from multiple measurements.

The original contribution of this study is two-fold. First, the R-ray parameters of the Q-D channel model obtained by the double-directional channel measurement in an indoor entrance hall environment are presented. Second, the validity of the model parameters of MiWEBA/IEEE 802.11ay [2, 3] obtained by only ray-tracing simulations in the similar scenarios to this study, is verified by comparing those with the parameters obtained by this measurement. Further, the discrepancy in parameters inferred from each scenario is discussed.

2 Data processing

2.1 Measurement scenario

Measurements were conducted at an entrance hall of a university building [4]. Fig. 1(a) shows the measurement scenario where the transmitter was installed near the glass wall and the channel responses were captured at 22 positions depicted by circle while sequentially moving the receiver. Note that the unfilled circles (#4, #12, #18 and #21) indicate the non-line-of-sight (NLoS) scenario. In the measurements, a full polarimetric $2 \times 2$ multiple-input-multiple-output (MIMO) channel sounder at the center frequency of 58.5 GHz was used. The signal bandwidth is 400 MHz (see Fig. 1(b)).

The double-directional channel impulse responses (DDCIRs) were obtained by directional scanning measurement using the horn antennas with the gain of 15 dBi.
2.2 Cluster identification

To derive R-ray parameters, random clusters were extracted from the measurement data as following. First, the multi-path components (MPCs) were extracted from the measurement data in high-resolution by using the sub-grid CLEAN algorithm [5] consisting of the global coarse search spans over the original measurement grid and the maximum likelihood estimation by using the fine sub-grid search. Fig. 1(c) shows the cluster identification results in Rx2 where the sub-figures show the color map of the measured angular power spectrum (APS), the MPC extraction result, and the clustering results from the top. Those are the results at the receiver side.
Here, the MPCs with close delays and angles were grouped by using K-PowerMeans clustering algorithm [6], and the MPC with the maximum power within a group (called cursor) was extracted as a cluster.

The scattering process of each cluster was identified by comparing the angle and delay power distribution with the photographs of the measurement environment. Based on the identified scattering processes, the clusters were classified into a D-ray or an R-ray. To be more specific, the clusters generated by line-of-sight (LoS) path, wall and ground reflection (up to double bounce), and wall-ground reflection are classified as a D-ray, and the other clusters are classified as an R-ray. The cluster #3 with a wall reflection were identified as D-rays, and the cluster #4, #6 and #5 with a pillar reflection and entrance wall reflection, respectively, were identified as R-rays. Fig. 2 shows the identification results of Rx2, Rx7, Rx14 and Rx20 with the power delay profile (PDP) and the ray-tracing results where the walls in light blue indicate the large objects which determine the geometry of the environment.

3 Derivation of R-ray parameters

The impulse response is simply expressed as a linear sum of the clusters including some strong D-rays and a few relatively weak R-rays. The impulse response with R-rays only is expressed as

\[ h(\tau) = \sum_{k=1}^{N_{\text{cluster}}} A_k e^{i \theta_k} \delta(\tau - \tau_k) \]  

where \( A_k \) and \( \theta_k \) denote the amplitude and phase of the cluster, respectively. \( N_{\text{cluster}} \) and \( \tau_k \) denote the number of clusters and the arrival time of the \( k \)-th cluster with respect to that of the LoS ray, respectively. In this section, the R-ray model parameters are determined.

At first, it is necessary to find the \( \tau_k \). In IEEE 802.11ay, it is assumed that the cluster occurrence follows a Poisson distribution, and thus the time difference of cluster arrival follows an exponential distribution. The time difference of arrival of the R-ray clusters are usually characterized by the cluster arrival rate \( \lambda^{-1} \) (average time difference of arrival) where \( \lambda \) indicates the number of clusters generated per unit time, which is a parameter of the Poisson distribution.

In addition, the cluster power was characterized by using a widely accepted exponential decay model as

\[ P(\tau_k) = |A_k|^2 = P_0 \cdot e^{-\frac{\tau_k}{\gamma}} \]  

where \( P(\tau_k) \) is the power of the \( k \)-th cluster. The power of the first arrival R-ray cluster, \( P_0 = P_{\text{LoS}} - K \) where \( P_{\text{LoS}} \) and \( K \) denote the power of the LoS path and the power difference between \( P_0 \) and \( P_{\text{LoS}} \) (called \( K \)-factor), respectively. The required parameters are the power decay constant \( \gamma \) and the \( K \)-factor. These parameters are obtained by a linear approximation with the least square method, which shows the relationship between the delay time versus the power gain of the R-ray clusters where \( \gamma \) and \( K \) correspond to the slope and y-intercept.

The parameters obtained from the above process are shown Table I. Note that \( N_{\text{cluster}} \), the number of R-ray clusters, was 3, which is the value that appears most
Fig. 2. Scattering process identification examples
Table I. R-ray parameters

| Parameter                  | IEEE 802.11ay [2] | This study |
|---------------------------|-------------------|------------|
| Number of clusters, $N_{\text{cluster}}$ | 5                 | 3          |
| Poisson arrival rate, $\lambda$ [ns$^{-1}$] | 0.01              | 0.04       |
| Power-dacay constant, $\gamma$ [ns]   | 15                | 10         |
| $K$-factor [dB]            | 10                | 13         |

often (mode). Compare with the parameters of the hotel lobby [2], which is a relatively similar environment to the entrance hall. The difference in cluster power parameters, which $\gamma$ and $K$-factor are relatively small. In contrast, the difference in $N_{\text{cluster}}$ and $\lambda$ are relatively large. It is thought that these differences result from the following reasons; 1) the actual environment in this study is more complicated than the simplified 3-D environmental model used for the existing models, and 2) dynamic range of the measurement system is limited. From these reasons, the number of observable clusters was also limited and thus the clusters with a long delay time could not be observed. Accordingly, it is possible that the time difference between R-ray clusters was relatively small. From the above comparison, it is seen that both the extracted parameters in this study and the IEEE 802.11ay/MiWEBA are reasonable values inferred from each corresponding environment.

4 Conclusion

In this letter, in order to develop a Q-D channel model for mm-wave access scenario at an entrance hall environment, we conducted measurement campaign to obtain the double-directional impulse responses. Collecting the cursors of the random clusters extracted via MPC extraction and cluster identification/classification from the measured data, the R-ray parameters were statistically derived. By comparing with the existing IEEE 802.11ay model, the validity of the proposed model was verified.

Acknowledgments

This research and development work was partly supported by the MIC/SCOPE #195004002 and the KDDI foundation.