P802.11  
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| Large Indoor Scenario (Entrance Hall) for 11ay Channel Models | | | | |
| Date: 2017-01-18 | | | | |
| Author(s): | | | | |
| Name | Affiliation | Address | Phone | email |
| Jian Luo | Huawei | Germany-Munich-Huawei Technologies Deutschland | +49-89-158834 | jianluo@huawei.com |
| Robert Müller | TU Ilmenau |  |  | Mueller.Robert@tu-Ilmenau.de |
| Yan Xin | Huawei |  |  | yan.xin@huawei.com |
| Kun Zeng | Huawei |  |  | kun.zeng@huawei.com |
| George Calcev | Huawei |  |  | george.calcev@huawei.com |

## Large Indoor Scenarios (Entrance Hall)

### Measurement Site

The entrance hall scenario corresponds to the measurements carried out in the Zusebau building at the Technische University Ilmenau (TU Ilmenau), see Figure 8‑5. The site represents a typical modern entrance hall of an office building, featuring a wide open area, a high ceiling height and three floors. The typical characteristic of the scenario is related to modern building which are primarily made of metal and glass. Furthermore, stairways between floors, concrete pillars and doors to offices and corridors are present. The entrance wall and left side wall are glass-steel constructions, whereas other walls are built of concrete. This measurement scenario is representative for application cases of 802.11ay WLAN systems, since similar building structures can be found in airports, train stations, hotel lobbies and entrance arrays etc. This reference scenario has the basic dimensions of 7m x 25m x 13m (WxLxH).



Figure 8‑5: Photograph of the Entrance Hall area of the TU Ilmenau

### Measurement Scenarios

In order to emulate a standard access scenario for WLAN application at 60 GHz, the transmitter (TX) was located in 3 different floors, acting as access points (AP), while the receiver (RX) was located in the ground level with different visibility conditions, acting as mobile user equipment (UE). The objective was to evaluate the propagation characteristics for the different heights at the AP side and the condition for different positions in LOS, OLOS (obstructed LOS) and NLOS. The measurements were split in two different scenarios. The first scenario emulates a general walk of a UE through the entrance hall with different heights of the AP. The second experimental scenario is concentrated on the deeper analysis of the 60 GHz channel regarding behaviour of a certain cluster. A sketch of both measurement scenarios is illustrated in Figure 8‑6, showing the TX and RX locations.

### Measurement System

The measurements were done with dual polarized circular horn antennas at the TX and RX sides. The half power beam width (HPBW) was 30° at both sides. Furthermore, positioners were used to scan the room in elevation and azimuth domain. The different measurement setups are also described in the following documents [1], [2], [3], [4], [5] and [6] at the IEEE mentor server. For the measurements, we use an M-Sequence-based baseband module with a 20 dB bandwidth of up to 7 GHz [7]. More details of the system are provided in [8]. The maximum-measureable dynamic range of the system at 60 GHz including the AGC and the antenna gain is around 200 dB. Fully polarimetric measurements were conducted, i.e. two orthogonal polarisations were radiated/measured at TX/RX stage. The polarisation at the TX was switched automatically, while the vertical and horizontal polarisations at the RX side were recorded in parallel. At any angular position of TX and RX and per TX polarisation, one impulse response is recorded at each RX polarization channel, which is called a snapshot.

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Figure 8‑6: Illustration of the locations of the transceivers in the entrance hall for first measurement scenario (left) and the second one (right)

### Measurement Results

Analysis was performed after an In-Situ calibration of the 60 GHz DP-UMCS. The large bandwidth enables the derivation of intra-cluster parameters and can provide an experimental verification method of Ray Tracing (RT) simulations. Another feature of the DP-UMCS is the high dynamic range which allows a deep insight in the 60 GHz channel. Here, only analysis of the 60 GHz vertical to vertical polarisation is considered. A fully polarimertic analysis is currently not possible due to the error in the dual polarimertic waveguide back-to-back calibration.

The delay spread (DS) has been estimated for all TX positions depicted in Figure 8‑6. The DS is calculated from the power delay profile (PDP) by considering only values that are at most 20 dB below the highest peak value. From this indoor measurement results, one can recognize double bounce reflections which are around 20 dB away from the Line-of-Sight (LOS), as shown inFigure 8‑7, Figure 8‑8, Figure 8‑9. Due to the increased occurrence of metal in modern building, the Delay Spread (DS) can be higher than 50 ns with a 20 dB threshold. The highest receiver power is found mainly in direction of the LOS components, i.e. in the direction of the maximum antenna gain. The DS for the NLOS measurement shows values from around 50 ns in our scenario, but the Excess Delay (ED) can be more than 200 ns.

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| Figure 8‑7: Synthetic Omni-PDP and Bi-Azimuth Profile Tx1 - Rx1 (LOS) from the second scenario | |
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| Figure 8‑8: Synthetic Omni-PDP and Bi-Azimuth Profile Tx1 – Rx4 (OLOS) from the second scenario | |
|  |  |
| Figure 8‑9: Synthetic Omni-PDP and Bi-Azimuth Profile Tx2 – Rx9 (NLOS) from the second scenario | |

### Parameter for Channel Model

Since the results of the first and second measurement scenarios have different setups, e.g. the first scenario did not have elevation scan at Rx, while the second scenario did include such elevation scan. Furthermore, the effective bandwidths of both results are different. Therefore, for simplicity, we currently only use the second scenario results to derive channel model parameters. Further work will be done so that both results can be exploited.

**Large Scale Parameters**

For channel modelling, the large scale parameters for the Q-D model were extracted for each Rx and TX locations. With a threshold of 20 dB, the MPCs of the channel were calculated from the measured data and indexed according to pathloss, delay spread (DS) with a 20 dB threshold, excess delay (ES), azimuth angle-of-arrival (AoA), elevation AoA, azimuth angle-of-departure (AoD) and elevation AoD. For the calculation of the excess delay, the noise floor was estimate by the following equation:

(8.1)

Equation: Noise floor estimation and removal Samples lower than the noise floor + 10dB are set to zero

The resulting values for the first and second measurement scenarios are described in Table 8‑2 and Table 8-3. Note that Tx 1-3 correspond to the Tx positions at the 3 floors, while the Rx positions are as indicated in Figure 8‑6.

Table 8‑2: Large Scale Parameters for the Entrance Hall Scenario second Measurement Scenario

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Tx | Rx | Visibility | DS\* [ns] | ED\* [ns] | AS at Tx [°] | Es at Tx [°] | As at Rx [°] | Es at Rx [°] | Received Power [dB] |
| 1 | 1 | LOS | 11.98 | 60.94 | 37.11 | 15.71 | 54.96 | 16.92 | -132.72 |
| 1 | 2 | LOS | 20.38 | 282.70 | 35.47 | 14.84 | 56.61 | 16.40 | -132.88 |
| 1 | 6 | LOS | 12.45 | 283.17 | 22.40 | 16.49 | 47.38 | 17.95 | -129.50 |
| 1 | 9 | LOS | 2.46 | 13.59 | 23.58 | 19.69 | 27.02 | 18.20 | -132.96 |
| 2 | 1 | LOS | 19.79 | 94.23 | 42.32 | 22.49 | 76.15 | 24.22 | -138.73 |
| Mean | | | **13.41** | **146.93** | **32.18** | **17.84** | **52.42** | **18.74** | **-133.36** |
| 1 | 3 | OLOS | 25.19 | 282.70 | 40.52 | 15.86 | 63.01 | 21.37 | -134.96 |
| 1 | 4 | OLOS | 31.40 | 134.55 | 55.09 | 18.71 | 84.43 | 20.66 | -136.98 |
| Mean | | | **28.29** | **208.62** | **47.80** | **17.28** | **73.72** | **21.01** | **-135.97** |
| 2 | 2 | NLOS | 20.45 | 87.67 | 43.73 | 20.93 | 70.34 | 25.47 | -137.25 |
| 2 | 3 | NLOS | 28.37 | 126.58 | 45.03 | 22.09 | 79.68 | 21.62 | -138.83 |
| 2 | 4 | NLOS | 32.31 | 143.46 | 40.75 | 20.62 | 76.47 | 19.43 | -141.20 |
| 2 | 5 | NLOS | 38.19 | 157.05 | 51.31 | 19.98 | 64.79 | 20.91 | -145.35 |
| 2 | 6 | NLOS | 33.90 | 167.37 | 43.63 | 18.12 | 50.05 | 18.70 | -145.72 |
| 2 | 8 | NLOS | 25.54 | 138.77 | 56.29 | 18.96 | 33.94 | 18.70 | -148.72 |
| 2 | 9 | NLOS | 25.54 | 124.24 | 49.44 | 20.34 | 45.13 | 19.24 | -149.75 |
| Mean | | | **29.19** | **135.02** | **47.17** | **20.15** | **60.06** | **20.58** | **-143.83** |

**Intra-Cluster Parameters**

In the 802.11ay channel model, intra cluster structure is added to the D-rays and R-rays base structure. Therefore, it is important to analyse the intra-cluster characteristics. Accordingly, the clusters can be roughly categorized into D-ray clusters and R-ray clusters, where the D-rays can be further categorized into Direct Ray (LOS), Ground Reflected Ray and additional D-Rays, such as first/second-bounce reflection rays from nearby walls. For simplicity, we categorize three types of clusters for simplicity: 1) Direct ray cluster (LOS cluster); 2) Other D-Ray clusters (strong reflections); 3) Random clusters. The following procedure has been used to extract the clusters and perform intra-cluster analysis:

1. Identify the LOS cluster and remove it from the channel data;
2. Identify the largest peak in the power domain of the residual channel (considering all the scan directions and delay components);
3. Define two regions based on the largest peak:
   1. Strong ray region (SR) that represents other D-Rays than the Direct-Ray: All the samples within a dynamic range of -20 dB to the largest peak;
   2. Random rays (RR): All the samples within -20 to -40 dB to the largest peak;
4. Sort the samples in decreasing order;
5. Select the sample with maximum power and identify its corresponding direction scan (beam). From the impulse response samples (after sample removal of step 6) of this direction scan (beam), a +/- 5 ns window is taken around this maximum sample. The samples within this window are identified as a cluster in the corresponding region;
6. From the residual channel samples (all the scan directions and delay components), eliminate all the samples that are within a 3-D window within 10 ns around the maximum sample (selected in step 5) and within the neighbouring two direction scans both in the azimuth and elevation, at both Tx and Rx. This step is to avoid that the same cluster is counted repeatedly, e.g. due to the sidelobes of the antenna pattern of the measurement antenna;
7. The delay spread is calculated from the 10 ns cluster that has been extracted in step 5;
8. Repeat step (4-7) until no more valid samples can be found in two regions defined above.

The two regions of rays defined above are also illustrated in Figure 8-10, which corresponds to Tx1-Rx1 of the second measurement scenario. For the above intra-cluster analyse, a dynamic range of 20 dB was selected. The noise floor estimation was done using the equation (8.1) as previously described. Figure 8-11 illustrates the output of the clustering procedure for Tx1 – Rx1. Table 8-3 shows the intra-cluster analysis results, with respect to per-cluster delay spread, for all the TX and RX pairs and all categories of clusters. As shown, although the synthetic omni directional DS can be up to 29.19 ns, the per-cluster delay spread is much smaller, i.e. between 0.69 and 1.90 ns. Furthermore, we can observe that the D-ray clusters have less variation in DS than the R-ray clusters.



Figure 8‑10: PDP showing the different regions of consideration of the rays



Figure 8‑11: Output of the clustering process for Tx1 – Rx1 indicating LOS (orange), SR (blue) and RR (red). The size of the balls is relative to the power.

Table 8‑3: Intra-Cluster Analysis Results

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
|  | | **LOS** | | **Strong Rays** | | **Random Rays** | |
| Tx | Rx | Mean Delay Spread | Var Delay Spread | Mean Delay Spread | Var Delay Spread | Mean Delay Spread | Var Delay Spread |
| 1 | 1 | 1.05 | - | 1.32 | 0.30 | 1.90 | 0.55 |
| 1 | 2 | 0.69 | - | 1.05 | 0.35 | 1.27 | 0.53 |
| 1 | 3 | - | - | 1.27 | 0.33 | 1.36 | 0.49 |
| 1 | 4 | - | - | 1.38 | 0.31 | 1.49 | 0.61 |
| 1 | 6 | 0.86 | - | 0.92 | 0.12 | 1.22 | 0.62 |
| 1 | 9 | - | - | 1.16 | 0.29 | 1.29 | 0.47 |
| 2 | 1 | 0.95 | - | 1.29 | 0.37 | 1.36 | 0.58 |
| 2 | 2 | - | - | 1.36 | 0.29 | 1.30 | 0.68 |
| 2 | 3 | - | - | 1.38 | 0.33 | 1.47 | 0.76 |
| 2 | 4 | - | - | 1.08 | 0.14 | 1.37 | 0.56 |
| 2 | 5 | - | - | 1.42 | 0.61 | 0.73 | 0.96 |
| 2 | 6 | - | - | 1.39 | 0.59 | 1.15 | 0.91 |
| 2 | 8 | - | - | 0.96 | 0.32 | 0.73 | 0.78 |
| 2 | 9 | - | - | 1.23 | 0.59 | 0.32 | 0.51 |
|  | Mean | 0.84 | - | 1.23 | 0.02 | 1.17 | 0.11 |

It is to be remarked that the influence of the antenna pattern is not fully removed in the above results. This can lead to limitations of the application of the above results. The main limitation is that the above results are only applicable to communication systems (802.11ay WLAN) with an antenna half power beam width (HPBW) of 30° or an integer multiple of 30°.

To relax such limitation, further measurements with more directional antenna as well as ray tracing/high resolution parameter estimation are needed.

**Backup:**

Table 8‑2: Large Scale Parameters for the Entrance Hall Scenario first Measurement Scenario

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Tx | Rx | Visibility | DS [ns] | ED [ns] | Tx Az [°] | Tx El [°] | Rx Az [°] | Prx [dB] |
| 1 | 1 | LOS | 25,99 | 161,72 | 71,59 | 56,07 | 85,69 | -1,81 |
| 1 | 2 | LOS | 32,66 | 207,45 | 67,52 | 55,09 | 79,99 | -2,27 |
| 1 | 3 | LOS | 39,82 | 142,15 | 65,09 | 49,19 | 83,05 | -2,44 |
| 1 | 4 | LOS | 40,03 | 155,09 | 65,66 | 49,51 | 77,27 | -0,88 |
| 1 | 9 | NLOS | 27,58 | 116,07 | 53,72 | 41,90 | 73,46 | -7,38 |
| 1 | 10 | NLOS | 42,51 | 213,33 | 69,15 | 46,17 | 80,95 | -7,39 |
| 1 | 12 | NLOS | 33,28 | 159,60 | 53,22 | 43,71 | 36,22 | -6,77 |
| 1 | 13 | NLOS | 59,02 | 200,39 | 70,16 | 51,07 | 34,60 | -13,13 |
| 1 | 14 | NLOS | 23,00 | 114,11 | 49,35 | 58,83 | 73,70 | 0 |
| 2 | 1 | LOS | 34,08 | 199,21 | 62,03 | 55,2 | 99,51 | -15,99 |
| 2 | 2 | LOS | 49,30 | 292,54 | 62,64 | 55,89 | 99,79 | -15,67 |
| 2 | 3 | LOS | 51,58 | 283,92 | 59,18 | 58,23 | 85,06 | -15,44 |
| 2 | 4 | NLOS | 35,55 | 196,07 | 64,01 | 54,79 | 82,75 | -17,05 |
| 2 | 9 | NLOS | 41,10 | 200,79 | 60,13 | 56,32 | 97,00 | -16,73 |
| 2 | 10 | NLOS | 46,54 | 242,15 | 57,19 | 53,05 | 73,85 | -18,36 |
| 2 | 12 | NLOS | 28,01 | 131,76 | 67,54 | 53,05 | 58,43 | -19,75 |
| 2 | 13 | NLOS | 36,43 | 325,09 | 73,56 | 56,83 | 45,67 | -21,67 |
| 3 | 1 | LOS | 49,83 | 203,13 | 50,89 | 58,64 | 92,61 | -12,98 |
| 3 | 2 | LOS | 46,07 | 281,56 | 40,15 | 59,03 | 93,54 | -12,61 |
| 3 | 3 | LOS | 37,65 | 270,39 | 54,58 | 60,41 | 73,94 | -13,32 |
| 3 | 4 | NLOS | 25,30 | 247,84 | 61,78 | 59,72 | 67,77 | -13,96 |
| 3 | 9 | NLOS | 42,62 | 183,13 | 38,32 | 56,15 | 83,87 | -14,42 |
| 3 | 10 | NLOS | 47,63 | 279,80 | 33.23 | 47,92 | 69,43 | -17,29 |
| 3 | 12 | NLOS | 24,31 | 190,58 | 52,96 | 60,75 | 32,20 | -18,93 |
| 3 | 13 | NLOS | 37,17 | 155,88 | 60,04 | 62,27 | 25,67 | -21,25 |

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