**IEEE P802.15**

**Wireless Personal Area Networks**

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| Abstract |  |
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#  Data Center

The wireless data center uses wireless data links to replace/complement the traditional cable connections, which brings various advantages e.g. high flexibility, low maintenance cost and favorable cooling environment. The high data rate requirement makes the THz technology a competitive candidate because of its high available bandwidth up to 50 GHz.

This document provides a realistic THz wireless channel model in a typical wireless data center scenario. The results presented here are based on [x9] and [x10].

As shown in , the scenario consists of many server chassis (we assume the standard 1U rackmount chassis in this document), 4 walls and a roof (the 2 front walls and the ceiling are set invisible to illustrate the chassis). The stack height is assumed to be 1.8 m whereas the distance between 2 chassis in the x direction is 0 and in the y direction is 0.5 m. The transmitter (Tx) and the receiver (Rx) are marked as blue circles. A ray tracing simulator is applied to generate the THz channel model. Details of this ray tracing simulator is available in [x11]. In our scenario, the material parameters of the wall and ceiling are taken from [x11] whereas the chassis is assumed to be a perfect conductor. The floor is believed to absorb the signal. Using the ray tracing simulator calibrated for the frequency 300 GHz, the propagation channel can be obtained. In figure 1, the propagation paths are illustrated as blue lines.



Figure 7: The data center scenario

## Propagation Path Types

 illustrates the possible propagation path types. When the antennas are located on the chassis roof, the signal can be transmitted in a Line of Sight (LoS) path (type 1), or reflected on the ceiling (type 2). In case that Tx and Rx are placed on identical or adjacent chassis, the antenna can be mounted below the chassis roof (type 3) and the propagation path is either LoS or via a reflector to reduce the interference on the propagation path type 1 and 2.

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Figure 8: Propagation path types

## Selection Between Path Types

When Tx and Rx are on identical or adjacent chassis, path type 3 would have advantage over type 1 and 2 because the lower antenna position produces less interference on other channels. If Tx and Rx are further departed therefore the antennas have to be placed on the chassis roof, type 2 is favorable if the propagation distance is limited whereas type 1 shows more advantage over a longer range. This selection is based on 2 considerations: 1) a shorter distance results in less free space propagation loss and therefore allows for additional reflection loss, 2) the elevation of path type 2 deviates from the horizontal direction more significantly with a shorter horizontal direction, therefore a vertically directive antenna would cause less interference on the horizontal LoS paths (because all the chassis have the identical size). We make the general suggestion that if the AoD/AoA elevation is at least 2 times the antenna Half Power Beam Width (HPBW) in the vertical direction away from the horizontal direction, type 2 has an advantage over type 1. The criterion should be adapted for every concrete scenario.

## Stochastic Channel Modelling

The stochastic channel modelling is based on massive ray tracing simulations. We choose a Tx position in the room corner (Tx 1) and in the room center (Tx 2) for propagation path type 1/2. For path type 3, we selected Tx and Rx positions randomly on identical or adjacent chassis.

Based on the simulation results, we derive a stochastic channel model in the following approach:

1. Determine number of propagation paths.
2. Assign a delay to each propagation path.
3. Determine the pathloss of each propagation path according to its delay.
4. Define the angular difference of each NLoS path to the LoS path.
5. Generate uniformly distributed phase for each path.
6. Generate frequency dispersion for each path.

In the following sections, we will explain the process step by step to obtain the stochastic channel model.

### Path Numbers

There is always 1 LoS path. The empirical distributions of the numbers of NLoS paths are presented in .

***Table 1 NLoS Path number distributions***

|  |
| --- |
| Type 1/2, Tx 1 |
| Number of paths | 17 | 18 | 19 | 20 | 21 |
| Probability (%) | 27 | 35 | 22 | 15 | 1 |
| Type 1/2, Tx 2 |
| Number of paths | 16 | 17 | 18 | 19 | 20 | 21 |
| Probability (%) | 32 | 29 | 12 | 16 | 8 | 3 |
| Type 3 |
| Number of paths | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 |
| Probability (%) | 22 | 13 | 8 | 15 | 8 | 17 | 8 | 6 | 3 |

### Delay distribution

 illustrates the delay distributions. Note that the LoS delay is the absolute value whereas the NLoS delay is the relative delay, i.e. the difference between the NLoS delay and the corresponding LoS delay.

|  |  |  |
| --- | --- | --- |
| paper/figures/delay_distribution/delay_distribution_type12_1.emf*(a) Type 1/2, Tx 1* | paper/figures/delay_distribution/delay_distribution_type12_2.emf*(b) Type 1/2, Tx 2*Figure 9: Delay distributions | paper/figures/delay_distribution/delay_distribution_type3.emf*(c) Type 3* |

 lists the distribution types and the corresponding parameter values.

***Table 2 Delay distributions***

|  |  |  |
| --- | --- | --- |
| Path | Distribution | Parameters |
| Type 1/2, Tx 1, LoS | Normal distribution | μ=2.26x10-8, σ=8.76x10-9 |
| Type 1/2, Tx 1, NLoS | Negative EXP | λ=8.76x109 |
| Type 1/2, Tx 2, LoS | Normal distribution | μ=1.20x10-8, σ=4.56x10-9 |
| Type 1/2, Tx 2, NLoS | Normal distribution | μ=2.98x10-8, σ=1.79x10-9 |
| Type 3, LoS | Normal distribution | μ=1.80x10-8, σ=8.60x10-9 |
| Type 3, NLoS | Negative EXP | λ=4.92x107 |

### Delay-Pathloss Correlation

The delay has a positive correlation with the pathloss, as depicted in . As in the last section, the pathlosses and delays for the LoS paths are absolute values whereas the NLoS carries relative pathlosses and delays. The definition of the relative pathloss is the pathloss of the considered path divided by the pathloss of the corresponding LoS pathloss.

|  |  |  |
| --- | --- | --- |
| *(a) Type 1/2, Tx 1* | *(b) Type 1/2, Tx 2*Figure 10: Delay-pathloss distributions | *(c) Type 3* |
|  |  |  |

 lists the correlations between delay and pathloss. The subscript “r” stands for “relative”. The correlation for the LoS paths can be completely described by the Friss equation. Therefore the random part is 0. For the NLoS paths, the additional loss due to reflections etc. contributes to the random part.

***Table 3 Delay-pathloss correlations***

|  |  |  |
| --- | --- | --- |
| Path | Deterministic part | Random part |
| Type 1/2, Tx 1, LoS | p=-20log10(d)-71.52 | σ=0 |
| Type 1/2, Tx 1, NLoS | pr=-0.294dr-17.44 | σ=4 |
| Type 1/2, Tx 2, LoS | p=-20log10(d)-71.52 | σ=0 |
| Type 1/2, Tx 2, NLoS | pr=-0.385dr-17.95 | σ=4 |
| Type 3, LoS | p=-20log10(d)-71.52 | σ=0 |
| Type 3, NLoS | pr=-0.429dr-30.30 | σ=6 |

With delays for every path available from the last section, the pathloss can be derived from .

### Pathloss-angle Correlation

The simulation shows some certain degree of correlation between pathloss and the angular difference between the considered NLoS path and the corresponding LoS path. This correlation is important because it has impact on the spatial filtering performance of the directive antennas. The correlations are depicted in Figure 11 and the numbers are listed in Table 4.

|  |  |  |
| --- | --- | --- |
| *(a) Type 1/2, Tx 1* | *(b) Type 1/2, Tx 2*Figure 11: Pathloss-angle correlations | *(c) Type 3* |
|  |  |  |

Table 4 Pathloss-angle correlation

|  |
| --- |
| Type 1/2, Tx 1 |
| Relative pathloss (dB) |
| Angular difference (°) | -70 | -60 | -50 | -40 | -30 | -20 | -10 | 0 |
| 0 | 0.000 | 0.000 | 0.054 | 0.062 | 0.065 | 0.014 | 0.257 | 0.000 |
| 10 | 0.000 | 0.000 | 0.023 | 0.029 | 0.082 | 0.067 | 0.274 | 0.360 |
| 20 | 0.000 | 0.000 | 0.000 | 0.020 | 0.052 | 0.061 | 0.031 | 0.360 |
| 30 | 0.000 | 0.118 | 0.008 | 0.058 | 0.113 | 0.082 | 0.120 | 0.280 |
| 40 | 0.000 | 0.000 | 0.000 | 0.031 | 0.084 | 0.055 | 0.067 | 0.000 |
| 50 | 0.000 | 0.000 | 0.023 | 0.036 | 0.039 | 0.084 | 0.036 | 0.000 |
| 60 | 0.000 | 0.118 | 0.078 | 0.016 | 0.030 | 0.131 | 0.016 | 0.000 |
| 70 | 0.000 | 0.059 | 0.085 | 0.062 | 0.047 | 0.178 | 0.000 | 0.000 |
| 80 | 0.000 | 0.000 | 0.109 | 0.102 | 0.131 | 0.090 | 0.000 | 0.000 |
| 90 | 0.000 | 0.059 | 0.132 | 0.122 | 0.080 | 0.027 | 0.023 | 0.000 |
| 100 | 0.000 | 0.059 | 0.070 | 0.049 | 0.049 | 0.033 | 0.031 | 0.000 |
| 110 | 0.249 | 0.059 | 0.078 | 0.049 | 0.039 | 0.027 | 0.029 | 0.000 |
| 120 | 0.000 | 0.059 | 0.062 | 0.067 | 0.026 | 0.023 | 0.020 | 0.000 |
| 130 | 0.249 | 0.176 | 0.101 | 0.084 | 0.026 | 0.020 | 0.022 | 0.000 |
| 140 | 0.249 | 0.000 | 0.047 | 0.067 | 0.025 | 0.019 | 0.015 | 0.000 |
| 150 | 0.249 | 0.235 | 0.062 | 0.062 | 0.032 | 0.017 | 0.013 | 0.000 |
| 160 | 0.000 | 0.059 | 0.039 | 0.027 | 0.027 | 0.027 | 0.015 | 0.000 |
| 170 | 0.000 | 0.000 | 0.016 | 0.029 | 0.029 | 0.027 | 0.019 | 0.000 |
| 180 | 0.000 | 0.000 | 0.016 | 0.026 | 0.024 | 0.019 | 0.013 | 0.000 |

|  |
| --- |
| Type 1/2, Tx 2 |
| Relative pathloss (dB) |
| Angular difference (°) | -70 | -60 | -50 | -40 | -30 | -20 | -10 | 0 |
| 0 | 0.053 | 0.000 | 0.026 | 0.017 | 0.054 | 0.015 | 0.021 | 0.000 |
| 10 | 0.053 | 0.000 | 0.000 | 0.017 | 0.070 | 0.027 | 0.041 | 0.051 |
| 20 | 0.053 | 0.000 | 0.053 | 0.044 | 0.093 | 0.045 | 0.079 | 0.039 |
| 30 | 0.053 | 0.000 | 0.053 | 0.048 | 0.075 | 0.123 | 0.100 | 0.000 |
| 40 | 0.053 | 0.000 | 0.026 | 0.065 | 0.074 | 0.089 | 0.108 | 0.100 |
| 50 | 0.053 | 0.000 | 0.026 | 0.072 | 0.050 | 0.065 | 0.121 | 0.248 |
| 60 | 0.053 | 0.000 | 0.053 | 0.075 | 0.060 | 0.056 | 0.137 | 0.129 |
| 70 | 0.053 | 0.000 | 0.132 | 0.140 | 0.055 | 0.035 | 0.165 | 0.000 |
| 80 | 0.053 | 0.000 | 0.184 | 0.130 | 0.051 | 0.117 | 0.085 | 0.003 |
| 90 | 0.053 | 0.748 | 0.145 | 0.106 | 0.093 | 0.065 | 0.034 | 0.039 |
| 100 | 0.053 | 0.000 | 0.066 | 0.072 | 0.039 | 0.054 | 0.023 | 0.071 |
| 110 | 0.053 | 0.000 | 0.000 | 0.027 | 0.043 | 0.053 | 0.020 | 0.058 |
| 120 | 0.053 | 0.000 | 0.053 | 0.041 | 0.056 | 0.056 | 0.012 | 0.058 |
| 130 | 0.053 | 0.000 | 0.092 | 0.068 | 0.045 | 0.034 | 0.013 | 0.039 |
| 140 | 0.053 | 0.000 | 0.039 | 0.041 | 0.046 | 0.035 | 0.012 | 0.045 |
| 150 | 0.053 | 0.250 | 0.026 | 0.010 | 0.030 | 0.029 | 0.013 | 0.026 |
| 160 | 0.053 | 0.000 | 0.000 | 0.000 | 0.028 | 0.041 | 0.005 | 0.058 |
| 170 | 0.053 | 0.000 | 0.000 | 0.014 | 0.023 | 0.031 | 0.007 | 0.019 |
| 180 | 0.053 | 0.000 | 0.026 | 0.014 | 0.016 | 0.027 | 0.006 | 0.019 |

|  |
| --- |
| Type 3 |
| Relative pathloss (dB) |
| Angular difference (°) | -70 | -60 | -50 | -40 | -30 | -20 | -10 | 0 |
| 0 | 0.062 | 0.045 | 0.000 | 0.000 | 0.000 | 0.000 | 0.003 | 0.002 |
| 10 | 0.000 | 0.091 | 0.049 | 0.054 | 0.005 | 0.006 | 0.000 | 0.000 |
| 20 | 0.125 | 0.136 | 0.024 | 0.027 | 0.005 | 0.004 | 0.000 | 0.000 |
| 30 | 0.062 | 0.091 | 0.024 | 0.000 | 0.016 | 0.000 | 0.004 | 0.003 |
| 40 | 0.000 | 0.091 | 0.073 | 0.000 | 0.033 | 0.013 | 0.006 | 0.006 |
| 50 | 0.000 | 0.136 | 0.000 | 0.000 | 0.030 | 0.006 | 0.047 | 0.028 |
| 60 | 0.000 | 0.000 | 0.049 | 0.000 | 0.025 | 0.011 | 0.013 | 0.006 |
| 70 | 0.000 | 0.000 | 0.000 | 0.054 | 0.027 | 0.032 | 0.003 | 0.047 |
| 80 | 0.000 | 0.000 | 0.122 | 0.000 | 0.019 | 0.015 | 0.131 | 0.069 |
| 90 | 0.000 | 0.091 | 0.439 | 0.675 | 0.692 | 0.877 | 0.780 | 0.820 |
| 100 | 0.000 | 0.182 | 0.049 | 0.000 | 0.005 | 0.004 | 0.004 | 0.001 |
| 110 | 0.062 | 0.000 | 0.049 | 0.081 | 0.033 | 0.000 | 0.001 | 0.002 |
| 120 | 0.125 | 0.091 | 0.073 | 0.000 | 0.033 | 0.002 | 0.000 | 0.005 |
| 130 | 0.187 | 0.000 | 0.024 | 0.081 | 0.027 | 0.004 | 0.003 | 0.009 |
| 140 | 0.062 | 0.000 | 0.024 | 0.027 | 0.025 | 0.000 | 0.003 | 0.001 |
| 150 | 0.187 | 0.000 | 0.000 | 0.000 | 0.016 | 0.000 | 0.000 | 0.000 |
| 160 | 0.062 | 0.045 | 0.000 | 0.000 | 0.005 | 0.006 | 0.000 | 0.000 |
| 170 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.019 | 0.000 | 0.000 |
| 180 | 0.062 | 0.000 | 0.000 | 0.000 | 0.003 | 0.000 | 0.001 | 0.000 |

The angular difference can be determined given the pathloss from the last section.

### Phase and Frequency Dispersion

The phase can be safely assumed to be uniformly distributed. The frequency dispersion can be described by

$$g\left(f\right)=\frac{g\_{0}f\_{0}}{f}$$

where f0 and g0 are the reference frequency and the channel gain at the reference frequency, respectively.

# Reference