## Modelling the mmWave Channel Based on Intelligent Ray Launching Model

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*Abstract*—Path loss modelling and prediction is essential in indoor network planning. To find an efficient and accurate path loss model benefits the network planning and optimisation process. In this work, we propose an efficient multipath empirical path loss prediction model based on an intelligent ray launching algorithm for 60GHz indoor channel. The comparison between the simulation result and measurement shows good agreement. This demonstrates that the proposed model is suitable for indoor network planning application.

Index Terms-antenna, propagation, measurement.

#### I. INTRODUCTION

Wireless network planning and optimisation is a key component in network deployment. To meet the demand of optimal network service with minimal resource and cost, network planning plays a key role in the deployment of the networks. Channel map is one of the key tools that are essential in the planning and optimisation of the networks geographically. The channel map is to indicate the channel characteristics over the geographic map of the network deployment space. The channel map is used as an essential tool to describe the channel condition geographically and then facilitates the network deployment in the design space.

Channel maps are widely constructed through computer simulation based electromagnetic propagation predication tools. One of the popular model to simulate the electromagnetic propagation is based on ray tracing. The early work [1] first introduced the simulation base channel predication software tools Wise. It is based on the electromagnetic propagation principles of geometrical optics (GO) and Uniform Theory of Diffraction (UTD). The software CINDOOR [2] is based on the same physical propagation simulation and is specifically designed for indoor environment. The work [3] extended the work to include diffusive diffraction in ray tracing. More recent work [4] also applied the ray tracing simulation to construct MIMO channels.

Another method is based on the numerical solution of the wave propagation equation and the Maxwell equations. The finite-difference time domain (FDTD) method gives a numerical solution to the electromagnetic field in time domain. Following the FDTD algorithm, the work [5] proposed a finite element based numerical method to build channel map efficiently. The millimetre wave (mmWave) channel is proposed as a promising technique for the future wireless networks. The channel has many unique characteristics. To deploy networks equipped with mm wave channels, a channel map construction tool that is capable of building mmWave channel map is essential. However, such a tool is still missing. In this work, we proposed a simulation based channel map construction tool based on an intelligent ray launching algorithm (IRLA) [6], especially for modelling the path loss value of 60GHz indoor channel. It exploits the characteristics of the mmWave channels to simplify the computational complexity of the traditional simulation tools, while still preserves high degree of accuracy of the original physical electromagnetic propagation models. The simulation model is then verified by the measurement result in a real propagation environment.

The rest of the paper is organised as follows. Section II described the new ray tracing based model. Section IV is the comparison and analysis of simulation. Section V is the conclusion.

#### II. THE PATH LOSS MODEL BASED ON RAY LAUNCHING

A widely used path loss model is the empirical model of log distance model. The model is simply given as

$$pl(d) = PL(d_0) + 10\gamma \log_{10}(\frac{d}{d_0})$$
(1)

where pl(d) is the path loss value at the distance d;  $PL(d_0)$  is the path loss value at the reference distance  $d_0$ ;  $\gamma$  is the path loss exponent. The path between the transmitter and receiver can be seen as the solely propagation path chosen in the model. Hence, the model can be seen as a single propagation path model. It is an empirical model widely used in modelling the path loss of propagation channel [7].

Wireless channel is widely modelled as multipath propagation. In multipath propagation model, the channel is written as

$$H(d) = \sum_{1}^{n} a(d)_i \exp(-j\theta(d)_i)$$
(2)

where H(d) is the channel impulse response at distance d; *i* is the multipath index; *n* is the number of the multipath components;  $a_i$  and  $\theta_i$  are the amplitude and phase of the *i*-th multipath component, respectively. For calculating the path loss value of the channel from the multipath propagation model, we have the path loss value at d as

$$pl(d)_{mp} = -\log_{10}|H(d)|^2$$
 (3)

In traditional ray tracing algorithms, the path loss value is calculated according to (3). The value of the total channel effect H(d) in multipath propagation is characterised through tracing the individual propagation paths. It is realised in GO and UTD [8]. However, the simulation of GO and UTD is computationally heavy. For the purpose of calculating the path loss value, we can adopt the simple log distance model in (1).

In our model, we calculate the path loss value of each individual multipath components via the log distance model. Thus the path loss value becomes:

$$pl(d)_{mpe} = \sum_{1}^{n} pl(d)_{i} = \frac{-\sum_{1}^{n} \log 10(|a(d)_{i})|^{2}}{n}$$
(4)

where  $pl(d)_{mpe}$  is the path loss value at distance d;  $pl_i$  is the path loss value of the *i*th multipath component. In appearance, the model in (4) differs from the model in (3). However, next we will show that the model in (4) is adequately accurate in comparison to the model in (3).

With a fixed distance d, we write the path loss value by (4) as  $\sum_{n=1}^{n} 10^{n} + 10^{2}$ 

$$PL_{mpe} = \frac{-\sum_{i=1}^{n} 10 \log |a_i|^2}{n}$$
(5)

and the path loss value from multipath propagation (3) as

$$PL_{mp} = -10 \log |\sum_{i=1}^{n} a_i \theta_i|^2$$
(6)

We define the difference between the two path loss values as

$$D = |PL_{mpe} - PL_{mp}| \tag{7}$$

In figure 1, the quantity d is plotted against the value of the path loss. The difference between the two models becomes negligible in the high path loss region. When the path loss values falls in the region above 20dB, the difference is smaller than 2dB. In this region, the path loss value calculated by (4) is a good approximation of the original multipath model.

This result shows that the model in (4) is adequately accurate in modelling the path loss values for channels in the path loss value region above 20 dB. To consider the realistic application of the model in network planning, the poor coverage where the path loss is high, is more to the interests of the network planning. Therefore the model offers a reasonable approximation to the original multipath propagation model. We can draw the following observation:

# **Proposition 1.** When the path loss values are in the region of larger than 20dB, the model in (4) is a good approximation to the model in (3).

The model in (4) calculates the path loss value of each individual multipath and average the values. The advantage is that the calculation avoid the complexity of modelling the environment for the GO and UTD and still considering the



Fig. 1. The Difference Between the Path Loss Values from Two Models



Fig. 2. The Difference Between the Path Loss Values from Two Models

multipath propagation mechanism of the wireless channel. By focusing on the path loss values, the computation can be significantly simplified without considering the GO and UTD. The drawback is that it is only suitable as an approximate model for the path loss values.

In 60GHz frequency band, the advantage of the model is even more obvious. The high path loss exponent of the 60GHz frequency makes the high path loss region significantly smaller. In path loss channel map construction, the model has higher accuracy in even vicinity regions of the network planning region.

The value of D against the distance is plotted in figure 2. The figure shows that the 60 GHz frequency band has significantly reduced the suitable distance of adopting the model in (4).

For 60GHz band indoor channels, we simplify the model in (4) by omitting the diffraction in the propagation. Thus the empirical path loss in the propagation calculation only consider the reflection and transmission in the propagation. The comparison between the simulation results and measurement in Section V shows this is an acceptable approximation in indoor path loss prediction.

The path loss of the reflected path is given as:

$$PL_{rf} = PL(d) - 10\log_{10}|\Gamma^2|$$
(8)

where PL(d) is the empirical path loss values through the distance d;  $\Gamma$  is the Fresnel reflection coefficient.

And the path loss value for transmission is given as:

$$PL_{tr} = PL(d) - 10\log_{10}|1 - \Gamma^2|$$
(9)

We use the three single path loss models in (1), (8) and (9) to calculate the path loss value in each multipath component. The path loss exponent value in (1) is chosen as  $\gamma = 2.2$  for an indoor office environment with 60GHz according to [7]. The individual path loss values from the multipath components are then used to obtain the total path loss values according to (4).

To trace the multipath propagation in the environment, we adopt an intelligent ray launching algorithm (IRLA) from [6]. The IRLA is based on 3D propagation environment modelling and ray launching algorithm.

#### III. CHANNEL MEASUREMENT

In this section, we briefly describe the channel measurement settings. The measurement environment is a typical office environment in the Department of Engineering at Durham University. The floor map is shown as in Fig. 3. The floor is carpeted. The doors are wooden. The windows contain metal frames. The walls are bricks with plastered outer layer. There are some inner walls and doors are replaced by glass. The ceiling is made of plastic material. An overview of the measurement environment is shown in Fig. 3.

The channel information is measured using the Durham channel sounder. The transmitter antennas and the receiver antennas are horn antennas. Both the transmitter and the receiver are equipped with 2 antennas. The height of the transmitter is 2.35m. The height of the receiver is 1.46m. The centre frequency of the measurement is 60GHz.

After the channel sounder was calibrated, the measurement was carried in the environment with the transmitter fixed. The location of the transmitter is indicated in Fig. 3 as point 'A'. The height of the transmitter is fixed at the ceiling to emulate the typical placement of an indoor wireless network access point. Various receiver locations are chosen. The receiver locations are drawn along the red line in Fig. 3 with various distance specified. The channel sounder data are recorded and processed. The path loss value at each measurement location is averaged over the 2 transmitter antennas and 2 receiver antennas. Thus, each measurement location has only one averaged path loss value.

#### IV. SIMULATION RESULTS AND COMPARISON

The simulation is carried out using the Ranplan iBuildNet radio propagation prediction tool. The environment is modelled in a 3D building structure. The indoor environment is



Fig. 3. Buidling Floor Map



Fig. 4. 3D Buidling Model

included in the model. The walls, doors, and windows are all included in the 3D building model. The 3D building model is shown in Fig. 4.

The simulation result of the path loss is shown in Fig. 5.

A 2D view of the path loss map is shown in Fig. 6.

The comparison between the simulation and the measurement result is shown in Fig. 7. The measurement locations are chosen along the red straight line in the map. In total 50 measurement locations are chosen. The simulation is set to 0.2m resolution.

In Fig. 7, the red curve is the simulation results. The blue curve is the measurement result. The simulation result give a good overall prediction of the path loss in the scenario. In most measurement locations, the error is below 3 dB. The overall Root Mean Square (RMS) error is 2.5028 dB. This demonstrates the simulation gives a good prediction to the



Fig. 5. 3D Path Loss Simulation Result



Fig. 6. 2D Path Loss Simulation Result

path loss values in the environment.

### V. CONCLUSION

In this work, we propose an efficient path loss model for 60GHz indoor channel. The path loss model is an implementation of multipath empirical path loss model based on ray launching algorithm. We choose a typical indoor office scenario to simulate the path loss values. Comparison between the simulation results and the measurement demonstrates that the proposed model is an accurate model for indoor channel path loss prediction in 60GHz band.



Fig. 7. Path Loss Value Comparison

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