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Propagation Characterization for Intra-ship Scenario towards 5G-enabled Smart Maritime

Xinjian Ou(1), Xinghai Guo(2), Ke Guan(2)(3), Ziang Ma(2) and Jingjing Liao(1)
(1) Wuhan Maritime Communication Research Institute, 430205 Wuhan, China
(2) State Key Laboratory of Rail Traffic Control and Safety, Beijing Jiaotong University, 100044 Beijing, China
(3) Frontiers Science Center for Smart High-speed Railway System, 100044 Beijing, China

Abstract

The fifth generation communication (5G) is expected to satisfy the communication demand of the smart maritime. In order to support the design and development of the intra-ship 5G communication system, it is important to characterize the intra-ship propagation at 3.5 GHz. In this paper, we present the path loss model for the intra-ship scenario at 3.5 GHz band. The scenario is divided into the line-of-sight (LOS) area, light none-LOS (L-NLOS) area and deep none-LOS (D-NLOS) area. Channel impulse responses are obtained by ray-tracing (RT) simulations. Propagation characterization of these areas is modeled separately, and the model coefficients are fitted based on the simulation data. Finally, the model is validated by new simulation data and compared with other relevant models. The results in this paper will help realize a high-quality 5G wireless coverage inside a ship towards smart maritime.

1 Introduction

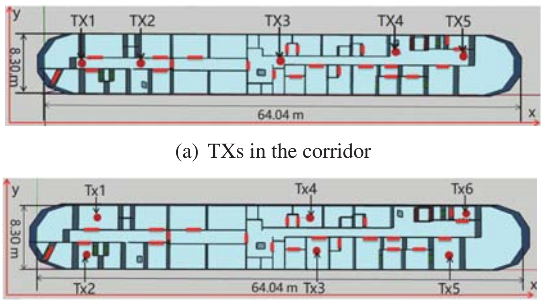
In the vision of smart maritime, the fifth generation communication(5G) enables ships and ports to have greater connectivity and reliability as well as share large amounts of relevant data [1]. 5G enables vessels to have greater connectivity and reliability. Thus, it is also needed by marine industry since the sensors and intelligent terminals can be installed flexiblely without cable systems [2]. Since wireless channels are the foundation for designing wireless communication systems, it is of vital important to understand the propagation channels for 5G communications. In [3], the one-slope model was applied to describe the propagation loss in intra-ship scenarios. However, the one-slope model should be modified because of the special environment with metallic walls in the intra-ship scenario [4]. Moreover, based on the composition of wave propagation mechanism, the scenario can be divided into different areas such as line-of-sight (LOS) area, obstructed-LOS (OLOS) area and none-LOS (NLOS) area [5]. As the most most widely used frequency spectrum, we choose 3.5 GHz as the research band.

The channel impulse responses can be obtained by ray-tracing (RT) simulations [6]. The simulation configuration should fully consider possible deployment positions of transmitters (TXs) and receivers (RXs). Both hatches opening and hatches closing scenarios are considered, and each scenario is divided into LOS area, deep-NLOS (D-NLOS) area, and light-NLOS (L-NLOS) area. Different models are established to describe the propagation loss of each area. The model proposed in this paper are validated by new simulation data and are compared with other relevant models.

The rest of the paper are organized as follows: Section II introduces the configuration of RT simulations. Section III establishes the path loss model. Section IV validates and analyses the presented model. Finally, we draw the conclusion in Section V.

2 RT configuration and simulations

CloudRT [7], a high performance RT simulation platform, is applied to simulate the wave propagation in the intra-ship scenario. The scenario is reconstructed as Fig. 1. Metallic doors are marked by read lines. The floor, walls and the ceil are all made of metal. The length, width and height of the scenario is 64.04 m, 8.30 m and 2.70 m, respectively.



(a) TXs in the corridor

(b) TXs in rooms

Figure 1. Scenario model Schematic

Five locations in the corridor and six positions in rooms are selected for TXs as Table 1 and Table 2. RXs are deployed in a 1.5 m high 1 m × 1 m grid, which starting horizontal and vertical coordinate is (4.5 m, 0.5 m). Each TX and RX adopts vertical polarization omni-directional antenna.

In RT simulations, reflection orders can greatly affect the accuracy of the results. The contribution of each order of reflection is calculated via RT simulations with reflected rays

Table 1. TX position in the corridor

TX ID	X [m]	Y [m]	Z [m]
Tx1	5.56	4.39	1.70
Tx2	13.55	4.04	1.70
Tx3	31.34	4.69	1.70
Tx4	47.57	5.87	1.70
Tx5	56.55	5.87	1.70

Table 2. TX position in rooms

TX ID	X/m	Y/m	Z/m
Tx1	8.41	6.66	2.50
Tx2	7.14	2.73	2.50
Tx3	36.91	2.08	2.50
Tx4	35.65	6.83	2.50
Tx5	53.61	2.07	2.50
Tx6	55.93	7.35	2.50

up to the 5th order in Fig. 2, which shows the combination of rays from 0 order of reflection to the 5th order of reflection. It can be seen that for most sampling snapshots, there is no essential difference between the 4th order of reflection and the 5th order of reflection. Thus, the highest simulation reflection order is determined as the 4th order.

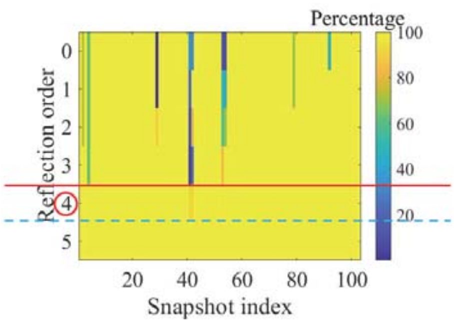
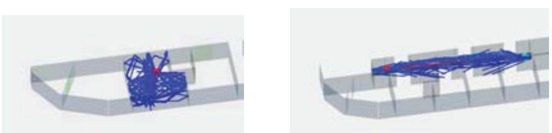


Figure 2. Contribution of different combinations of rays

The simulations are conducted after completing the relevant configuration. RT simulations are conduct for four cases: A) TXs in the corridor, hatches closed; B) TXs in the corridor, hatches open; C) TXs in rooms, hatches closed; D) TXs in rooms, hatches open. Case A, B, C and D are used in the rest of paper to refer to these four cases. One of the snapshot simulated by RT is shown in Fig. 3, in which the lines are traced rays.



(a) TX in the room (b) TX in the corridor

Figure 3. One snapshot of RT simulations

3 Propagation characterization

In this paper, the intra-ship scenario is divided into the LOS area, L-NLOS area and D-NLOS area. The LOS area is the area with the direct path. The L-NLOS area is the area without the direct path but with a transmission path and other reflected and scattered paths. The D-NLOS area is the area with only one transmission path.

3.1 Path loss modeling for the LOS area

The model of the LOS area is based on the one-slope model with shadow fading. The Gaussian random variable which represents the shadow fading is adopted to modify the path loss model. The model is established as follows:

$$L = L_0 + 10nlog_{10}d + X_\sigma \quad (1)$$

where L denotes path loss in dB, L_0 is the reference loss value per unit distance, n denotes path loss index. d is the distance from TX to RX in meters. X_σ is Gaussian random variable where the mean value is zero and the variance is σ. Using the principle of nonlinear least squares, the value of model coefficients is derived from the simulation results with the minimizing mean square error criterion. Coefficients in four cases are shown in Table 3.

Table 3. Path loss model coefficients of the LOS area

Tx	Hatches	Case	L_0	n	$\sigma[dB]$
Corridor	Closed	A	39.59	1.50	5.39
Corridor	Open	B	40.1	1.72	4.89
Room	Closed	C	40.78	1.08	5.89
Room	Open	D	39.78	1.80	5.32

3.2 Path loss modeling for the L-NLOS area

For the L-NLOS area, the penetration loss of transmission path and the shadow fading caused by reflected and scattered paths should be considered at the same time. In practical systems, if the path loss is too high, the signal will drown in the thermal noise. Thus, the path loss greater than 175 dB is discarded. Moreover, the path loss varies greatly in the case of the transmission path penetrates one or two walls. Therefore, the path loss of the L-NLOS area should be modeled as follows:

$$L = L_0 + 10n'log_{10}(d) + M \times L_{trans} + X_{\sigma'} \; M = 1 \; or \; 2 \quad (2)$$

where n' denotes path loss index in this area. M denotes the number of penetrated walls. L_{trans} is the penetration loss value of the metallic wall, which takes 40 dB. $X_{\sigma'}$ denotes the shadow fading, which is a Gaussian random variable with mean value is 0 and the variance is σ'. There are few receive points in the L-NLOS area in case A and C. Thus, only the coefficients of case B and D are given as follows:

Table 4. Path loss model coefficents of the L-NLOS area

Tx	Hatches	Case	M	L_2	n	σ
Corridor	Open	B	1	32.79	1.30	7.12
Corridor	Open	B	2	31.40	1.92	14.46
Room	Open	D	1	12.08	1.52	6.40
Room	Open	D	2	13.29	3.51	14.22

3.3 Path loss modeling for the D-NLOS area

For the D-NLOS area, the penetration loss caused by the blocking between each TX and RX needs to be considered. As the penetration loss is proportional to the number of walls penetrated, the model established as follows:

$$L = L_0 + 10n'' log_{10} d + M \times L_{trans} \quad (3)$$

where n'' denotes path loss index in this area. The values of the parameters are obtained as follows:

Table 5. Path loss model coefficients for the D-NLOS area

Tx	Hatches	Case	L_0	n''
Corridor	Closed	A	42.72	21.14
Corridor	Open	B	43.55	21.05
Room	Closed	C	43.93	18.78
Room	Open	D	43.99	18.53

4 Model validation

In order to validate the presented model, new simulations are conducted to obtain new data as test sets. The presented models are compared with relevant general models. The new RX positions are deployed on a 1.5 m high 1 m $\times$ 1 m grid, of which starting coordinate is (4.8 m, 0.2 m).

4.1 Model validation of the LOS area

The new simulations results, presented model and free-space path loss (FSPL) model of the LOS area are compared as Fig. 4. It can be seen that for cases A, B and D, the good agreement between simulation and model can be found in the whole distance. The metallic room in the intra-ship scenario is very small, so path loss of the LOS area is more influenced by reflections and scattering caused by metallic walls in case C. In all four cases, the model slope is less than the slope of FSPL model because the metallic ship reflects and scatters a large number of multipaths which decrease the path loss.

4.2 Model validation of the L-NLOS area

Typical indoor path loss models of the NLOS area are available in WINNER and ITU-R [8]. The WINNER model is expressed as (4):

$$PL(d) = 44.42 + 36.8 log_{10}(d), \ \sigma_{SF} = 3.5\, dB \quad (4)$$

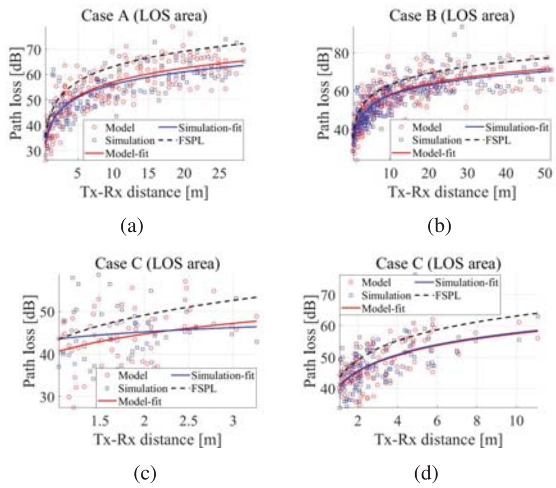


Figure 4. Results comparison of the LOS area

where d is the distance in meters from the TX to the RX, and σ_{SF} is the shadow-fading standard deviation. The ITU-R model is as follows:

$$PL(d) = 20 log_{10}(f) + N log_{10}(d) + L_f(n) - 28 \quad \sigma_{SF} = 10 \sim 12\, dB \quad (5)$$

where N denotes the distance power-loss coefficient, which takes 28 at 3.5 GHz. f is the carrier frequency in MHz d denotes the distance in meters from the TX to the RX ($d > 1\ m$). L_f is the the floor-penetration loss in dB, and n is the number of floors between the TX and the RX. In this scenario, all TXs and RXs are in the same floor, then equation (5) can be simplified to:

$$PL(d) = 20 log_{10} f + 28 log_{10}(d) - 28 \quad (6)$$

The new simulation results, the presented models, ITU-R model and WINNER model are compared in Fig. 5.

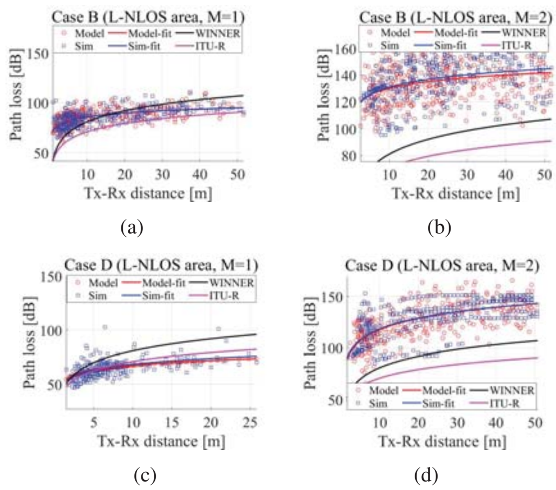


Figure 5. Results comparison of the L-NLOS area

It can be seen that in all four cases there is a good agreement between model and new simulation results. When the transmission path penetrates one wall, the WINNER model and ITU-R model are close to simulation results. When the transmission path penetrates two walls, the two models' prediction results are lower than simulation results.

4.3 Model validation of the D-NLOS area

For D-NLOS area model validation, The WINNER indoor model and the ITU-R indoor model are chosen to compare with the presented model. The models and simulation results are shown in Fig. 6. It can be seen that there is good

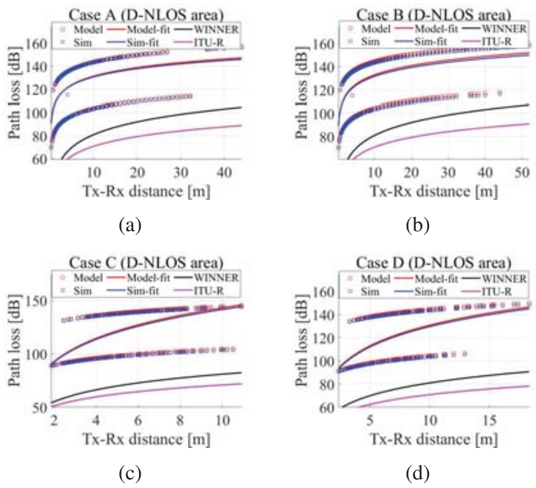


Figure 6. Results comparison of the D-NLOS area

agreement between simulation and model prediction in the whole distance. ITU-R and WINNER model underestimate the path loss because the metallic walls make the penetration loss higher than the general indoor situation. The error analysis in terms of the root mean square error (RMSE)is in Table 6. It can be seen that the RMSE of the presented

Table 6. RMSE of models in each case

Case	Presented [dB]	WINNER [dB]	ITU-R [dB]
A	1.22	57.56	29.79
B	1.65	55.93	30.72
C	0.10	53.95	31.30
D	4.50	54.23	30.1

model is less than 4.5 dB in all four cases, which means it is sufficiently accurate to predict the path loss model of the D-NLOS area. The RMSE of the WINNER model and ITU-R model is beyond their shadow-fading ranges, which means they are not suitable to predict the path loss of the D-NLOS area in this scenario.

Overall, the models can accurately predict the path loss for the LOS area, D-NLOS area and L-NLOS area, and can be more accurate than WINNER model and ITU-R model.

5 Conclusion

In this paper, the wave propagation of the intra-ship scenario at 3.5 GHz is characterized through RT simulations. The path loss model of the LOS area, L-NLOS area and D-NLOS area is established separately. The presented models are validated and compared to other relevant models. The presented models can accurately predict the path loss of each area with the RMSE less than 4.50 dB. This implies the presented model can be appied to characterize the propagation in the intra-ship scenario.

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