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Multi-Path Propagation Prediction of 433MHz Wave in the Ship Environment Based on the Ray-Tracing Model

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Abstract. Designing a stable wireless sensor network with reliable transmission is a key issue for wireless communication applied in the complex ship environment. The traditional network node deployment mainly relies on human experience along with multiple tests and leads to very long construction period. The current work established a three-dimensional ray-tracing model of the 433MHz wave transmission in an engineering ship. The multi-path propagation prediction results were compared with the on-site test of wireless channel using LoRa communication devices. Then the deployment scheme of the transmission and reception nodes was proposed to facilitate the signal stable transmission. It could provide an effective theoretical guidance for the network construction.

Keywords. Ship cabin, LoRa, ray-tracing method, multi-path propagation

1. Introduction

With the development of smart ships and unmanned ships, digital sensors and numerical control devices are widely used. Instead of the cable transmission, the application of wireless sensor networks based on the Internet of Things (IOT) for ship has been studied extensively over the past few years [1-2]. With low power, easily assemble devices and sensor modules, it becomes a potential low cost alternative for traditional cabling networks. So far, researchers mainly use Zigbee technology or LoRa (Long Range) technology to design the network [3-4].

The ship cabin is usually large and the equipment are placed in the relatively fixed position when the vessel is assembled. The monitoring sensors of cabin equipment are deployed with little change. Thus the wireless signal propagating in ship cabin mainly includes diffraction and reflection [5]. The longer the wavelength, the stronger the ability to diffuse the large obstacles. Besides, due to the abundance of metal equipment in the complex ship environment, the signal power loss could not be ignored.

LoRa is a kind of ultra-long-distance wireless transmission scheme based on spread spectrum technology. Compared to the Zigbee technology, it has unique advantage with longer transmission distance, longer battery life and better pass-through ability [6-8]. It has been proved its stable working performance for ship-based measurement system [9-10]. Thus it could be well employed in various cabins of the ship with a good application prospect. This paper analyzed the LoRa band (433MHz frequency band here)

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propagation in an engineering ship based on the ray-tracing method. It aims to provide the propagation prediction and some deployment guidance for the network design, different from the traditional way which mainly relies on human experience along with multiple on-site test and lack of effective theoretical analysis.

2. Multi-path Propagation Prediction of LoRa Band in Engineering Ship Cabin

2.1. Ship cabin model establishment based on the ray-tracing method

Prior simulation-based studies based on the indoor path loss model would help to predict the wireless channel propagation and would greatly reduce the cost of network construction. Ray tracing algorithms has computational advantages and high accuracy, and are used widely in graphics and mobile communication analysis. Details about the electromagnetic theory can be found in the published literatures [11]. It has been validated an effective method of the communication analysis in indoor complex environment [12]. The propagation prediction can be carried out by the comprehensive analysis of reflection, transmission, diffraction of each tracking ray. This group previously investigated the 2.4 GHz wireless channel propagation in the ship cabin and the simulated results were consistent with the experimental results [13]. In the present work, the 3D-dimensional model of the real engineering ship cabin "Zhaoming wheel" (shown as Figure 1) was established and the multi-path propagation prediction of wireless signal at 433MHz frequency band was carried out based on the ray-tracing method. All simulations reported here were performed using the Remcom Wireless InSite commercial software package[14].

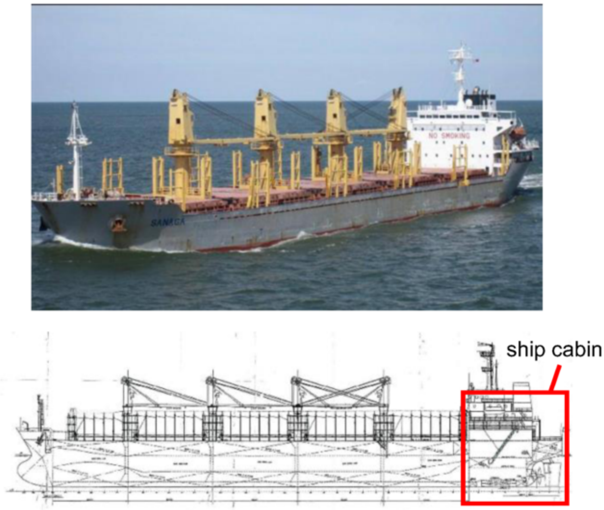

Figure 1. Side view of "Zhaoming Wheel"

The "Zhaoming wheel" is 169m length and 13.6m moulded depth with 43m maximum height. Figure 2 showed the ship cabin structure. The main engine was located at the middle area of the bottom floor, and the hollow staircase leading to the second platform was arranged on one side; The second-floor platform surrounded the main engine and was arranged with a control room and the corridors, the ship auxiliary engine was located at the tail of this platform. The accommodation area was above the third platform and the ship wheelhouse was at the top. Figure 3 showed the deployment of the transmitter (Tx) and receiver (Rx). The transmitter was placed at the bottom platform of the main engine room. The receivers were placed at various areas including: bottom floor of cabin (Rx1, Rx2), outside the control room (Rx3), accommodation area1 (Rx4), accommodation area2 (Rx5), ship wheelhouse (Rx6) and the weather deck (Rx7). The receivers Rx3, Rx4 and Rx5 adopted 16 receiving nodes forming a rectangle shape, respectively.

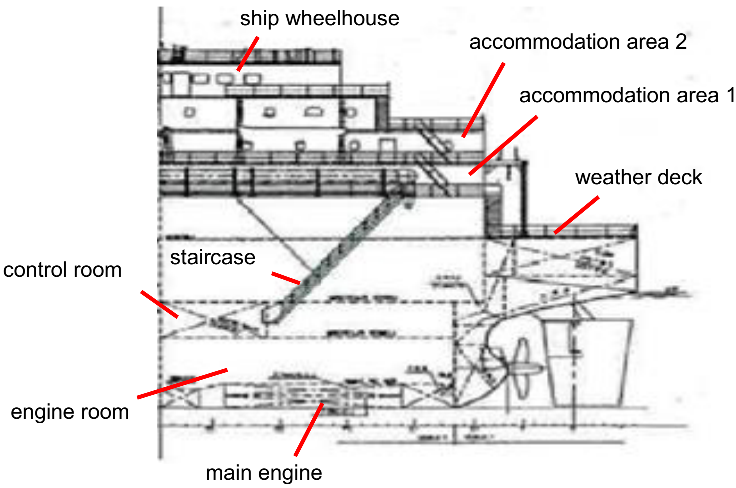

Figure 2. Ship cabin structure

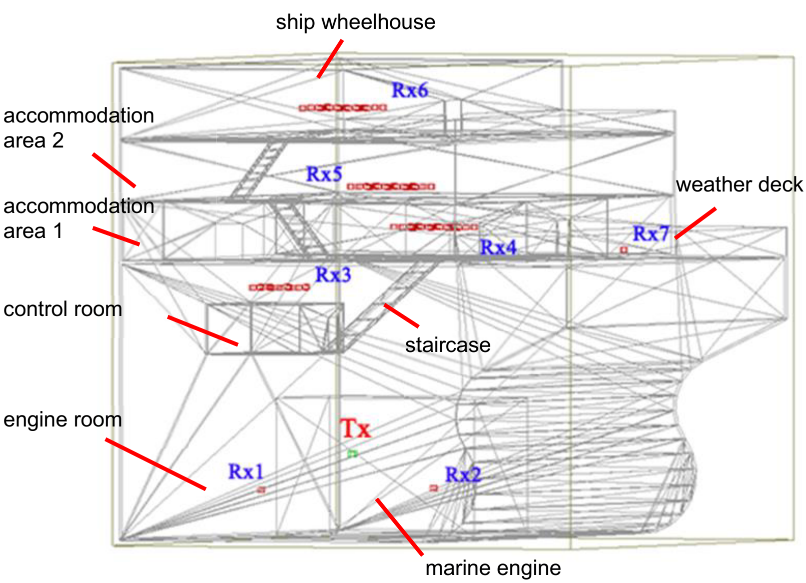

Figure 3. Deployment of the transmitter and receiver in ship cabin

The material of structure and equipment was set as steel. The doors between floors were open and set as fireproof material and were. The windows of the control room were made of glass. An omnidirectional monopole antenna working in vertical polarization mode was adopt with sinusoid wave shape of the transmitting signal. Other simulation parameters were shown in Table 1.

Table 1. Simulation parameter

parameter	value
Signal frequency	433MHz
Transmit power	20dBm
Transmitter	Linear monopole omnidirectional antenna
Receiver	Linear monopole omnidirectional antenna
Antenna gain	15dBi
Reflections	5
Transmission	2
Refraction	1

2.2. Propagation results

Both Rx1 and Rx2 have good reception since the receivers were located at the same layer as the transmitter. While the receiver Rx6 and Rx7 had bad reception because they were far from the bottom floor. And the Figure 4, Figure 5 and Figure 6 were the multi-path propagation results of Rx3, Rx4 and Rx5, respectively.

As can be seen from the results, while the floor height increases, the effective transmission path decreases significantly, as well as the signal strength. For the Rx3 located outside the control room, the minimum receiving power -30dBm occurred at the #1 receiving node, which represented the innermost position of the area. The multiple reflections caused the large energy loss. Except that, the other receiving node could get good reception due to the staircase which could provide the favorable transmission channel. For the Rx4 located at the accommodation area1, there were some receiving nodes (region 2) with poor reception because they were far from the hatch and several activity rooms and cubicles distributed in this floor. It obviously increased the reflections and consumed a lot of signal energy. For the Rx5 located at the restaurant in the accommodation area2, the fluctuation occurred on the various nodes (from the -13.5dBm to -250dBm). However, the receiver was relatively high and far from the transmitter at the bottom floor and most nodes had relatively poor reception. The region 3 even had no effective propagation path.

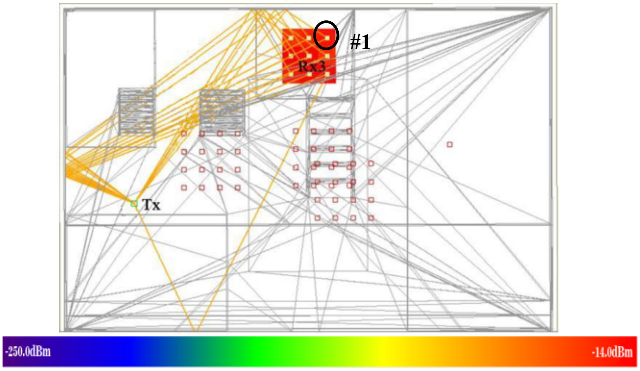

Figure 4. Propagation result of the receiving nodes of Rx3

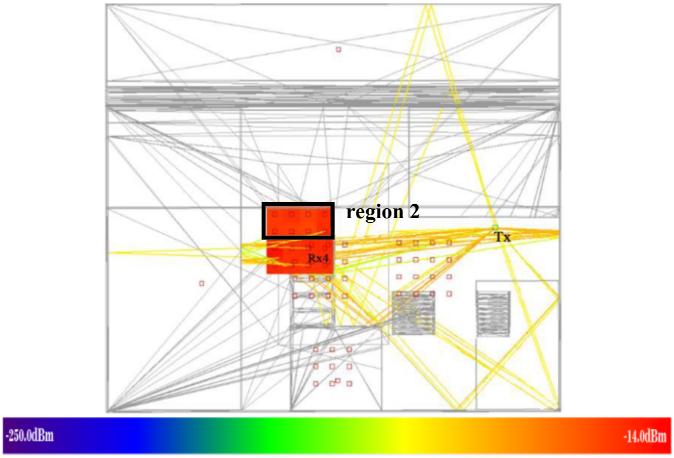

Figure 5. Propagation result of the receiving nodes of Rx4

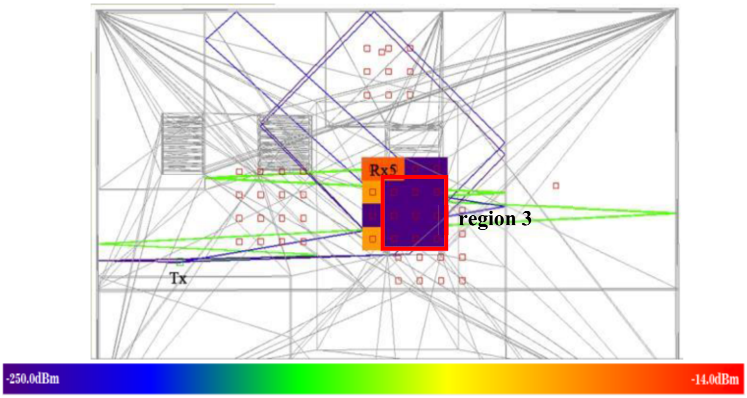

Figure 6. Propagation result of the receiving nodes of Rx5

The experimental point-to-point test using the LoRa communication devices was also carried out in the ship cabin of ‘Zhaoming Wheel’, shown as Figure 7. The measurement area was the same as the simulation[15]. The reception situation was shown in Table 2, as well as the simulated result. The comparison showed that although the model couldn’t fully represent the actual complicated ship structure, the simulation analysis was relatively consistent with the experiment. It means that propagation prediction based the proposed method could play effective guidance for real network.

Figure 7. Experimental test using the LoRa communication devices

Table 2. LoRa communication situation of the ship cabin

Receiver	Reception (simulation)	Reception (experimental)
bottom floor (Rx1、Rx2)	good	good
control room (Rx3)	good	good
accommodation area1 (Rx4)	normal, partly no reception	normal
accommodation area1 (Rx5)	poor, partly no reception	normal, partly data packet loss
ship wheelhouse (Rx6)	no reception	poor, seriously data packet loss
weather deck (Rx7)	poor	poor, seriously data packet loss

From the simulated and experiment result, some deployment scheme of the transmission and reception nodes can be concluded to facilitate the signal stable transmission. The analysis can provide a good reference for the network deployment. Although the transmitter and the receivers was set at the different platforms, some receiving points within the adjacent layers could get good reception, especially with the help of the hollow staircase. However, it was still recommended that one gateway base station should be arranged on each cabin platform when constructing the network. It was only responsible for the communication with the nodes within this platform to ensure the stable signal transmission. In addition, in the same cabin platform, the location of the transmitter and the receivers should avoid the diagonal position of the large equipment obstacles. If it is really unavoidable, it was better to set another relay node for relay transmission of the collected data.

3. Conclusion

This work investigated the multi-path propagation of 433MHz wave transmission in an engineering ship cabin based on the ray-tracing method. According to the structure drawings combine with the cabin equipment measurement, the three-dimensional ray-tracing model of the 433MHz wave transmission in the ship cabin was established. The transmitter and receivers were set at the various locations. And the propagation characteristics was investigated. Besides, the on-site point-point test of wireless channel using LoRa communication devices was carried out in the engineering ship and the reception was recorded. The comparison indicated that the propagation perdition based on the established model could be consistent with the experimental results of each cabin layer. The variance between the simulated model and the real ship unavoidable existed, however the simulated result would provide effective guidance for the practical signal transmission in the ship. For the complex ship environment, the prior simulation analysis was recommended because the network deployment could skip the unfavorable locations for the signal transmission. The simulation-based studies of wireless channel propagation in ship were an effective and low-cost way and would play an important role for the wireless sensor work construction.

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