TransNav
http://www.transnav.eu
the International Journal on Marine Navigation and Safety of Sea Transportation
Volume 10
Number 2
June 2016
DOI: 10.12716/1001.10.02.03

The Comparison Study on AIS Signal Reception Rate with Directional Antenna and Omni Antenna

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ABSTRACT: With the wide use of AIS system in the world, especially in ports and the waters with heavy traffic, AIS message loss may be related to environmental conditions, obstacle, limitation of VHF technology and AIS network overload, thereby reducing the AIS signal successful reception rate. This paper selected typical AIS data received by Yagi and Omni antennas at the same time in specific waters, uses grid and AIS data recovery technology, establishes the AIS signal coverage model, analyzes signal reception rate of Yagi antenna and Omni antenna of AIS base station, and verified the superiority of Yagi antenna in AIS signal reception rate.

1 INTRODUCTION

AIS is the abbreviations for Automatic Identification System, it consists of shore base facilities and ship-borne equipment. The basic operations of AIS are "ship-to-ship" and "ship-to-shore" information exchanges, and it can also handle multiple communications with a fast updating rate. The AIS data exchanged are divided into three different types referring to literature[1,2]:

- Static data,.
- Dynamic data,.
- Voyage-related data,.

AIS base station is widely used around the world, especially in ports and areas with large traffic flow. AIS data may be lost due to environmental conditions such as rain or fog, and obstacle conditions such as shadowing caused by landmasses or other vessels, limitation of VHF technology, AIS network overload, etc. Therefore, the successful reception of ships' AIS signal will be reduced, which caused a hidden peril of marine safety. According to the literature [3]，the report interval of ship-borne AIS equipment should meet the requirements of relevant standards. However, the data received by AIS base station seldom meets the requirement because of the adverse impacts from the transmission characteristics, power, the status of the base station, geographical features, etc. Many scholars have done a lot of researches on AIS network data link capacity, network congestion and slot reservation selection algorithm, but no one has solved these problems in the view of practical application. AIS uses the SOTDMA algorithm to fit the high density of communications, and to ensure the reliability and real-time communications operations. But due to the restrictions of SOTDMA which is described in literature [3], when the number of ships is beyond its rated number or the coverage of AIS user signals overlaps with each other, there will be a time slot conflict which often causes a large missing of AIS information and obstruction in signal sending and receiving , thus affecting the safety of navigation. IMO published a model course which contains an exemplary calculation about the theoretical capacity of AIS devices. This number is based on ideal assumptions meaning that each vessel is able to reserve time lots whenever needed according to the reporting intervals .Since AIS data are often used for manual collision avoidance and vessel movement prediction, it is important that AIS reporting intervals are kept as described in ITU (2010). On the basis of analysis of the historical data of AIS in Shanghai Port about 30% of vessels failed to update their positions for 2 minutes, 15% for 3 minutes, 10% for 5 minutes, and 5% for 15 minutes in literature [5].

Currently, most AIS base station antennas are Omni antennas which have small gain, the effective distance is about 30nm and the signal receiving range is 360° all around. The signal loss are easily to be occurred when the density of ship is huge. However, directional antennas have a large gain and effective in a given direction. Directional antennas have been used in many fields such as mobile communication, satellite navigation, aviation communication, radio and television and so on, which overcomes the shortcomings of the Omni antenna and achieves satisfactory results which have been mentioned in the literature [6]. But so far directional antenna hasn't been used in the marine industry. This paper focuses on the AIS antenna and analyses the advantages of AIS directional antenna in practical application. To identify the antenna influence of AIS data loss the following aspects are being evaluated within our work:

- General comparison and analysis of the AIS message reception rate of both AIS antennas at the same time and place
- Evaluating AIS dynamic data reception rate in different distance
- Detailed evaluation of AIS signal coverage.

2 TECHNICAL BACKGROUND

AIS utilizes SOTDMA access method to broadcast and receive ships' dynamic and static data automatically for the purpose of realizing the identification, monitoring and communication. AIS base station system receives ships' data and navigational status and broadcast hydrological, meteorological and other information released by the management department to ships at the same time, to manage and provide service for the ships within the area.

2.1 *Principle of SOTDMA*

SOTDMA algorithm AIS is introduced in literature[3].SOTDMA algorithm is the core technology of AIS, it bases on TDMA technology. The TDMA technology divides time into periodic frames, each frame is divided into several time slot, and the information of the ship is transmitted to each mobile station in a specified time slot of a frame on principle of certain time slot allocation. Every ship can choose a time slot which does not conflict with other ships without the control of the base station to release own information independently. Any ship within the AIS range will be able to send or receive message reports from all ships (shore stations) without interfering with each other. According to IMO model course in the literature [4], theoretically AIS system can accommodate the data of 450 ships at the same time and when the system is overloaded, the further targets from own ship will be abandoned so as to ensure the priority of close range target. AIS users can use the free time slot selection algorithm to write the obtained reservation time information into the slot reservation information message to actualize the information sharing with other users. Every user can send their own time slot reservation information periodically and receive the message from other users to achieve information sharing, so the status of time slot is constantly updated. When the communication channel is free, the idle time slot is easy to find. But when the channel is busy, there may be a slot collision, because several AIS terminal may make synchronously an appointment of the same time slot. Under the SOTDMA protocol it is inevitable that the situation of overlapping occur when many users choosing time slots, leading to failure for a single or several users to transmit-receive messages. With the wide application of AIS system, the load of AIS data link are increasing, and all those have resulted in a significant increase in the collision rate of time slots. If the ratio of time slot collision increases to a certain degree, the reliability of AIS system will be greatly affected.

Currently, existing AIS equipment has been unable to solve the problem of AIS slot collision. It is necessary to explore new methods to improve the receiving efficiency of AIS signals. Therefore, we intend to increasing AIS reception rate by replacing Omni antennas with directional antennas within experiment.

2.2 *Antenna type of AIS base station*

According to different coverage of power or radiation field, AIS antenna can be divided into Omni antenna and directional antenna, of which the biggest difference is the directional gain. The most important indicator of measuring antenna is the performance of the gain. The way to measure antenna gain is to polymerize the electromagnetic waves beam emitted by the antenna, and then divide the value at the same point on the received power , or the ratio of the major lobe of the radiation density and the radiation density in isotropic when the output power equal to each other. Antenna gain is related to the width of the major beam of electromagnetic waves. The narrower the major beam of antenna, the smaller the side lobe and tail lobe and the higher the gain of major lobe direction. The gain of the antenna is inversely proportional with the radiation range.

1 AIS Omni antenna
   Omni antenna means homogeneous radiation in horizon in directions of 360°, which usually means non-direction. Because antenna gain is inversely proportional to the radiation range of the antenna, Omni antenna gain is worse, usually below 9 dB. AIS Omni antenna has the same gain in different directions. It causes a lot of technical shortcomings, such as the high probability of slot collision, transmit power usage insufficient and interference between send and receive signals and so on. Currently, AIS base station basically uses Omni antenna.

2 AIS directional antenna

Directional antenna means radiation in a certain direction in horizon, which is usually described as directional. Directional antenna has better electromagnetic effect from one or several specific directions, and the electromagnetic waves from other directions is very tiny. Similar to Omni antenna, the smaller the beam width is, the greater the gain benefit is. The directional antenna was generally applied in the circumstance of long distance communication, small coverage, high target density.

Usually, the main purpose of directional antenna is to enhance the anti-jamming capability. Comparing with Omni antenna, directional antenna is more sufficient in utilizing power. Under the same circumstances, directional antenna can transmit and receive signals further than Omni antenna does in given direction. It will reduce the probability of the slot collision when transmitting message by using a directional antenna. And the high gain beam can be generated in a certain direction so as to reduce the probability of occurring time slot interference and increase greatly the throughput capacity of network and the number of subscribers. All these unique advantages listed above provide a new approach in solving time slot collision interference.

3 AIS DYNAMIC DATA PROCESSING TECHNOLOGY

In total, there are 27 types of AIS message. Each type of AIS message serves a specific purpose, e.g. message type one, two and three represent the dynamic data of Class A system including the rate of turn, heading, speed over ground or the navigational status. The AIS data are also used as an additional overlay, e.g. on radar or ECDIS screens. The AIS reporting intervals may vary depending on the AIS message types and vessel's state. The dynamic data of Class A system are sent in the form of position reports within the AIS message types one, two, and three as shown in Table 1 according to ITU (2010).

Table 1. Reporting intervals of class A system position reports

Vessel state	Interval
At anchor/moored and not moving faster than 3kn	180s
At anchor/moored and moving faster than 3kn	10s
0 kn≤SOG≤14 kn	10s
0 kn≤SOG≤ 14 kn and changing course	4s
14kn＜SOG≤ 23 kn	6s
14kn＜SOG≤ 23 kn and changing course	2s
SOG＞23 kn	2s
SOG＞23 kn and changing course	2s

Because of the delay and message loss of AIS dynamic data updating, it is necessary to process the data, evaluate the difference of received AIS signal from the AIS base station. The corresponding geographic grid structure should be established for the specific waters to adopt a certain algorithm to evaluate the AIS data reception rate in different regions.

3.1 *Interpolation algorithm for ship's AIS motion state*

Ship's AIS motion interpolation can recover AIS dynamic data, which is of much importance for ship's traffic data analysis. Making use of the vector function to express the relationship between time and space coordinates, its tangent line and its change rate can reflect the direction and speed of the ship motion as well as their acceleration and other physical characteristics. According to the known ship dynamic data to optimize the ship motion vector parameters, then the ship motion state interpolation model is established to realize the interpolation of the dynamic data of the ship at any given time. Refer to the literature[5],many factors such as vector function of Ship's motion state, interpolation model of Ship's motion state and calculation on ship's acceleration must be considered into.

3.2 *Grid of research waters*

In order to evaluate the effect of AIS signal received by AIS base station in a given water, all the data shall be classified accurately according to geographical position in researched area. Quadtree index is one of the commonly used spatial indexes in geographic information system. This paper refers to the Quadtree data structure index, and divides the studied area into a number of sub regions of equal size.

3.3 *AIS Coverage algorithm*

International scholars has carried out a lot of researches work for AIS coverage. In literature [7] and [8], they put proposed a new method of estimating AIS signal coverage from the receiver terminal, using interpolation method based to recover error messages in AIS transmission;. In literature[9], the author proposed the Grid-Count algorithm, using AIS historical data, interpolation algorithm and grid technology, which can be more efficient in calculation of AIS base station signal coverage.

Grid-Count algorithm is adopted in the analysis of AIS signal coverage. Grid of the water area near a AIS base station, select the target ship, get the grid of the AIS data sent, and calculate the number of the single ship which has been sent to the grid map. Using interpolation algorithm in literature[5], calculate the AIS message that should be sent from the target ship , then obtain the grid map of number of signal; Compare each the grid map of number of AIS signal, finally form the AIS signal coverage grid frequency map of the waters near the base station; AIS base station signal coverage is determined by the number of signals sent or to be sent from the near base station; Fill in with colors according to the frequency value of the size of the grid frequency map.

In order to obtain the message coverage grid graph, we can calculate the total number of data messages sent or to be sent in each grid, on the premise that the number of data messages sent or to be sent by several vessels is known. Assume that in the i grid，the total number of packets sent is S_i，the total number of packets should be sent is t_i after the interpolation，and then the signal coverage rate in the area is indicated as r_i： $r_i = s_i / t_i$.Fill in the grid with colors according to the size of the coverage rate to create a map of grid coverage. Utilizing Flex technology to correspond the grid map to the actual geographic coordinates, we can directly observe signal coverage of the AIS base station in the related waters .

The experiment and performance are described within the following section.

4 EXPERIMENT AND PERFORMANCE

To precisely evaluate AIS message received by directional antenna and Omni antenna , we select the typical data received by AIS base station in Tianjin , China as object of study, and evaluate the signal receiving effect of AIS base station in aspects of total quantity of message, dynamic data and signal coverage. In the experiment, we select Yagi antenna as directional antenna. The AIS antenna installations have been done according to IMO guidelines. To minimize negative effects on the reception rate, the two sets of AIS equipment are the same condition except AIS antenna.

4.1 *Characteristics of AIS base station antenna*

Table 2. Parameter of AIS shore station antenna

parameters	Yagi antenna	Omni antenna
Frequency	162M	162MHz
VSWR	1.15	1.2
Input impedence	50Ω	50Ω
Gain	16.6dBi	6.7dBi
Signal direction	40°（major lobe）	360°

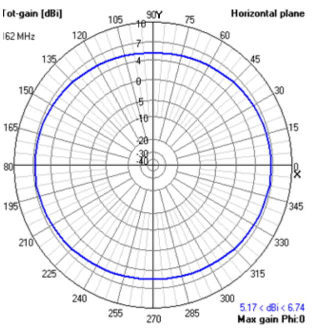

Figure 1. Horizontal directional signal radiation of Omni antenna

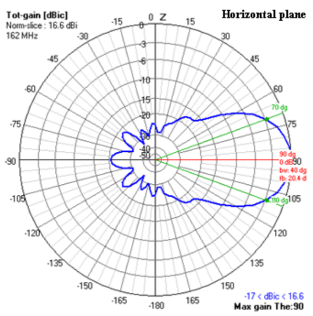

Figure 2 Horizontal directional signal radiation of Yagi antenna

The characteristics of AIS shore station antenna is showed in Table 2, Fig. 1 and Fig.2, it is obvious that the gain of Yagi antenna is much better than that of Omni antenna, but signal coverage scope is much less than the latter. In general， higher gain will result in higher reception rate than lower one.

5 ANALYSIS OF EXPERIMENT RESULTS

The results of the experiment can be divided into three aspects. The first one deals with general comparison about all the message reception rates of the two antennas. The second one is about the evaluation the AIS dynamic data reception rate in different range. The last one has a detailed research on AIS signal coverage.

5.1 *General comparison quantity of data received by both antennas*

The AIS messages received from 00:00 to 24:00LT on 24th, Oct, 2015 by AIS base station in the experiment. All the messages have been received by two AIS antennas as shown in Table 3.

Table 3. AIS message count of Yagi antenna and Omni antenna.

AIS ID	Message meaning	Yagi	Omni
1,2,3	Position report class A	4528547	1311878
5	Static and voyage related data class A	331231	98909
18	Standard class B position report	467980	112666
19	Extended dynamic data class B position report	23999	6836
24	Static and voyage related data class B	132554	32014
Other		521998	150340
Total		6006309	1712643

Comparing the count of AIS message the Yagi antenna has received 2-4 times more data than Omni antenna did in different period. The result showed in Fig. 3.

The quantity of data received by Yagi antenna is always larger than that of Omni ones in different periods for all the day. During period 0900-2100, Omni antenna performs well relatively, but Yagi antenna's reception is 2-3 times more, which is 4 times at other period of the day. As expected, the higher gain the antenna is, more AIS messages have been received.

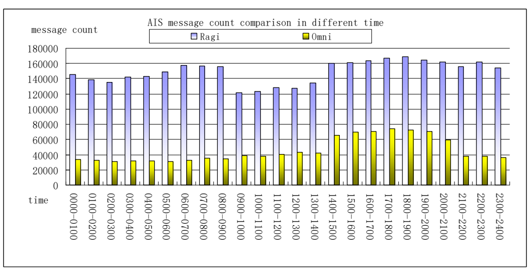

Figure 3. AIS message count comparison in different time

5.2 *Evaluation of the AIS dynamic data reception rate in different distance*

Since the dynamic data contains latitude and longitude data, it is possible to calculate the reception distance for both antennas. According to all Class A position reports as shown in Fig.3. To explain further the difference between Yagi antenna and Omni antenna in receiving AIS message , we divided all position reports of Class A into different ranges, and there is a big difference among them.

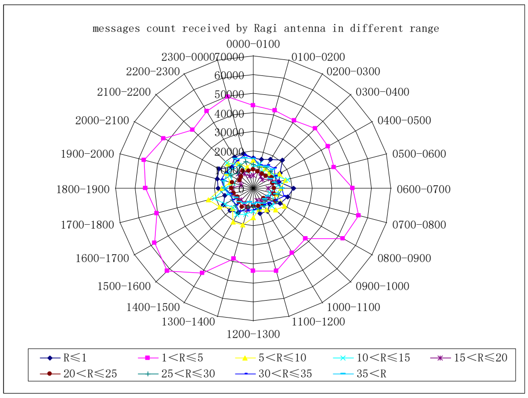

Figure 4. Dynamic data reception rate in different ranges by Yagi antenna

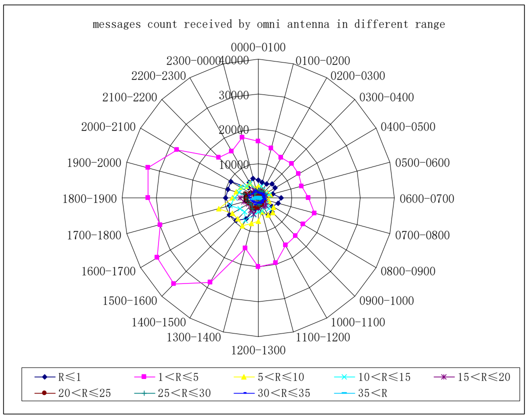

Figure 5. Dynamic data reception rate in different ranges by Omni antenna

In different ranges measured between the position of vessel and AIS base station, the quantity received by Yagi antenna is always more than Omni antenna did. The result is showed in Fig.6.

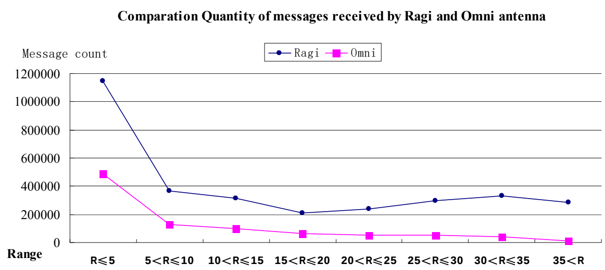

Figure 6. AIS dynamic data count comparison

With the increase of the distance between the vessel and AIS base station antenna, the amount of AIS data received by Yagi antenna does not significantly decrease. But with the increase of the distance, the AIS data received by omni antenna gradually decreased, and the AIS shore station antenna is almost unable to receive the AIS data of the ship when the distance is more than 35 nm. And with the increase of distance, the performance advantage of Yagi antenna receiving AIS signal is more and more obvious. The count of data received by the Yagi antenna is about 2 times as much as that of the Omni antenna within 10 nm.. Between 10 nm and 30 nm, the count of data received by the Yagi antenna is about 4 times as much as that of Omni antenna. At a distance of more than 30 nm, the number of data received by the Yagi antenna is about 10 times as much as that of the Omni antenna.

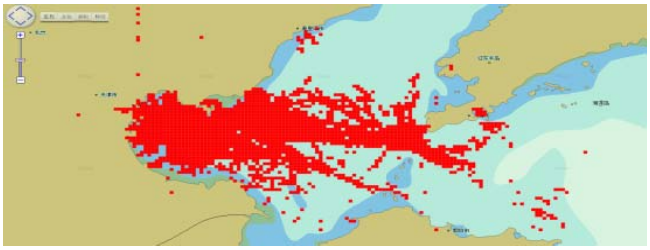

Figure 7. Vessels' AIS trajectory received by Yagi antenna

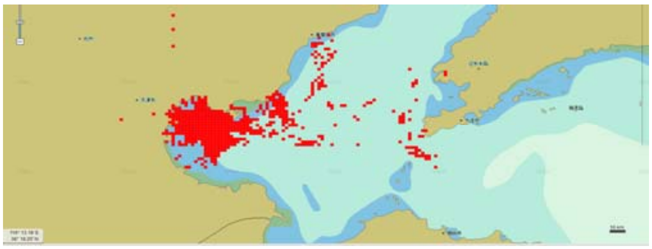

Figure 8. Vessels' AIS trajectory received by Omni antenna

Overlay vessel motion trajectory on the electronic chart as is shown in Fig.7 and Fig.8, the quantity and distance of data received by Yagi antenna are much larger and longer than that of Omni antenna.

5.3 *AIS signal coverage*

We select AIS base station in Tianjin port as the experimental object. It is the center on position of exact geographical location Lat:38°58′32″8N, Long:117°47′14″E, the water is divided into 60×60 grids, 2 nm×2 nm each grid. Use Grid-Count algorithm to obtain all the single ship signal grid maps, and finally generate the grid frequency map of the base station signal coverage. The major lobe of AIS Yagi antenna direction is 110°.The color of the grid in Fig. 10 and Fig. 12 is different, which represents signal coverage rate in different location. The scale of signal coverage corresponds to different color. In Fig.9 and Fig. 11, the vertical coordinates is the AIS coverage, the horizontal coordinates is the corresponding number of grid. The non-grid range indicates areas where no ships passing by, of which the signal coverage rate is 0.

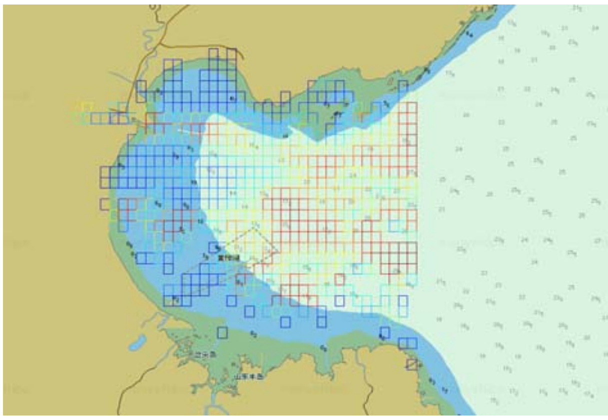

Figure 9. AIS signal coverage grid frequency chart of the Yagi antenna

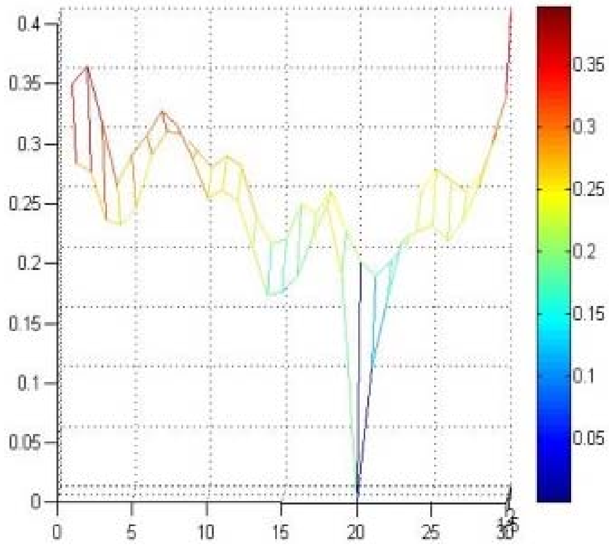

Figure 10. Yagi antenna signal coverage trend chart （ horizontal section direction is 110° ）

According to Fig. 9 and Fig. 10, Yagi antenna AIS signal coverage increases with the change of the distance. Within 20 nm, the AIS signal coverage rate is 36%-22%; between 20 nm to 40nm, the signal coverage rate is 20%-25%; and between 40 nm to 60 nm, the signal coverage rate is 20%-40%. It proves that the AIS Yagi antenna has obvious directivity. It is restricted by the direction of the major lobe. The coverage rate of AIS signal in short range is low, whereas with the increase of distance, the directional advantage is obvious. With the increase of the distance and decrease of ship's density, the coverage rate of AIS signal is increased within the AIS signal coverage range.

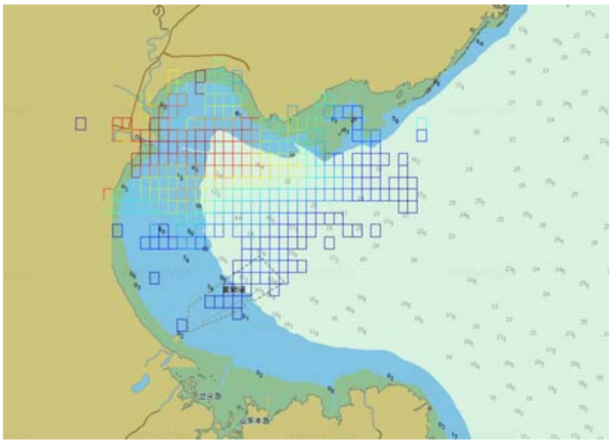

Figure 11. AIS signal coverage grid frequency chart of the Omni antenna

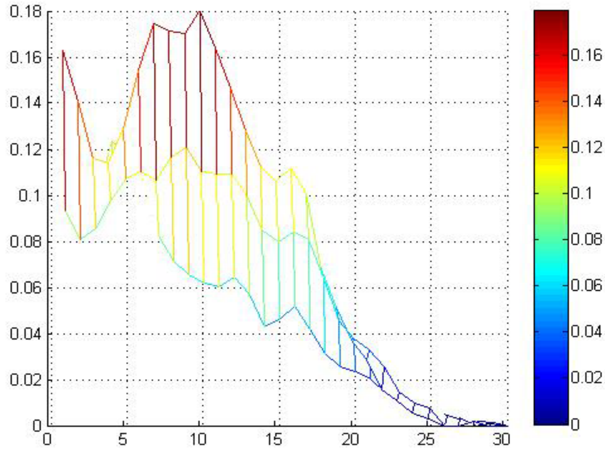

Figure 12. Omni antenna signal coverage trend chart (horizontal section direction is 110°)

According to Fig. 11 and Fig. 12, with the increase of distance, the coverage rate of AIS Omni antenna gradually reduced. Within 20nm, the AIS signal coverage rate is 8%-18%; between 20-40nm the signal coverage rate is 4%-18%; and the signal coverage rate is 1%-4% beyond 40 nm, Due to the influence of mores ships in short range and the slot collision of AIS signals, the AIS coverage rate of Omni antenna in close range is very low. And with the increase of distance, AIS signal intensity is weakened further, and thus AIS signal coverage rate is further reduced. The coverage rate of AIS signal received over 60 nm is less than 1%.

6 CONCLUSION

Through the evaluation of AIS data received by two AIS antennas in Tianjin AIS base station, we found the fact that the directional antenna has more advantages in receiving AIS message in the count, distance and signal coverage than Omni antenna under the same conditions. The directional antenna may make up the deficiency of the Omni antenna in the AIS data reception rate, reduces the message loss and efficiently increase the signal coverage range and reduce the AIS signal blind area in ports and the waters with heavy traffic.

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