PER Estimation of AIS in Inland Rivers based on Three Dimensional Ray Tracking

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ABSTRACT: The Automatic Identification System (AIS) is an important maritime safety device, which is populous in inland rivers. Compared with that in open sea, the Package Error Rate (PER) of AIS in inland river has increased sharply due to its complex environment. With the help of hardware in loop simulation, it is possible to make statistical calculation on the PER under a given field strength and describe the data by quadratic rational fraction. Meanwhile, in the three dimensional software environments, the signal field strength is able to be calculated by the ray tracking method, which exhausts all the possible propagation paths, including direct way, reflection, diffractions, and the other medium attenuation matters. Beyond that, in the model, the propagation geography information in inland rivers is required to be simplified in some way, or the computation of the ray tracking is too hard to get. The paper set the Changjiang Wuhan channel as the field testing region, and all the deviations are less than 5% in sunny weather, which proves the method accurate and effective.

1 INTRODUCTION

The Automatic Identification System, or in short AIS, is a rising safety equipment in maritime navigation and positioning, and originally designed for the military use, working on the frequency 161.975 MHz and 162.025 MHz, transmitting power 12.5 W and 2 W (K. Naus et al. 2007). The AIS modulate the data at the speed of 9600 bps, and the mode is GMSK (Guassian Minimum Shift Keying), which means high efficiency (Yan Xinping et al. 2010). The AIS terminals in 20 nautical miles share the 2 frequency in the TDMA (Time Division Multiple Access), which divides one minute into 2250 pieces as the channels, supports them exchanging the name, call sign, ID number, size, speed, vector, ROT and so on. As a highly integrated wireless equipment, the AIS covers the dead zones of RADAR, making the navigation much more reliable. In 2006, the AIS is suggested to

be a fundamental equipment in newly built ships by IMO (Tao Linmin et al. 2004).

When the AIS is adopted in inland-rivers, the AIS becomes a maritime management device, more than a navigation tool, but also face some new problems (Wang Feizhou et al. 2001). First, the inland river would cause observable attenuation on the AIS signal, which would make the AIS data link less reliable than that on the open sea. As well as that, the AIS data package contains the CRC checksum, but no error tolerance, which means any bit error, would make the whole package invalid.

Some researches are representative as below. With the help of hardware-in-the-loop simulation, it is possible to find the relationship between the PER and AIS signal receiving field strength, and prove that in specific distance or above, the AIS data link turns out to be unreliable (Ma, 2009). Considering the

uncertainty of AIS data link, there is a limitation of the AIS messages in some area, such as the port, the anchoring berths, and it is also possible that all the AIS network would be overloaded, that no AIS messages could be transmitted (Zhang, 2010). To solve the problem, the AIS terminals could adopt intelligent transmit power to minimize the coverage to protect the AIS data link, based on the present AIS targets number and the distance to the basestations (Ma, 2009). However, majority of the researches about AIS did not take the reliability into account; they totally believe the AIS track shows how the targets moved. Some researchers adopt the AIS signal as an instance to prove the radar target, and find how to combine them into one object (J.F.Vesecky, 2009). In the maritime management area, some organization takes the AIS signal as a source to do the statistics on the vessels traffic flow, looking for features about the channels (K.Hasegawa, 2008). The other researchers analyze the AIS data to find out the collision risk (Lin Changchuan, 2008). According to the all the details above, it is obviously that the AIS is fundamental information for all the maritime area, some organizations have been doing the researches on the reliability. Their essays show that, field strength estimation would be the chief problem of AIS reliability estimation. It is a pity that, there is no paper to discuss the AIS field strength propagations estimation model.

To solve the problem, the paper proposes a method to estimate the field strength of the AIS signal based on the ray tracking. The second part discuss the simulation platform, and the third part shows the three dimension ray tracking method, the last part proposes a filed testing.

2 THE RELATIONSHIP BETWEEN PER AND THE SIGNAL FIELD STRENGTH

In the research of RF system, the simulation is very common, which includes the software simulation and hardware-in-loop simulation. The software simulation is more popular in two areas, one is the performance study in specific hardware circuit, such as the ADS suite from Aglient, the Pspice from ORCAD, which is designed for improve the products and lower the development cost (Dzvonkovskaya A et al. 2010).

The software mentioned are very limited in the AIS study, for the AIS usually covers a large area which is more 80 km, contains varieties of dimensions, even two completely same terminals would show different performance in very small change in environment. The simulation focus on the micro view of AIS terminal is meaningless. Meanwhile, the inland-river environment stands for the complex landforms, the GSM and CDMA simulation tools are unable to describe the un-continuous transmission medium. So the AIS performance is unable to be studied by the software simulation, the hardware-in-loop simulation may be the key (Grasso R 2010).

The hardware-in-loop simulation introduces the real target into the process, which use the real transmitter as the simulating model, combines the

hardware and software. In the RF studies, this kind of simulation is very common in the military areas, such as the radars, the guided weapons. The most outstanding characteristic of this simulation, is it can simulate very complex transmission process.

The AIS is very suitable to use the hardware-in-loop simulation, for it is just the system which contains very complex transmission environment.

The structure of the simulation is designed as Figure 1, which includes the software and hardware. The hardware contains the signal source, attenuation simulator, interference simulator, and receiver. And the software would control all the hardware to simulate the attenuation and interference in specific environment.
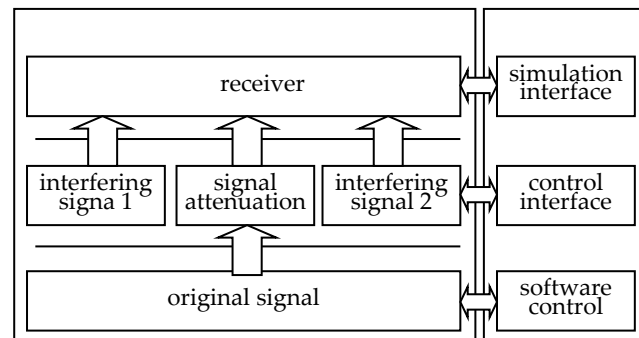

Figure 1. Hardware-in-the-loop simulation system structure of radio frequency

The real hardware-in-loop AIS simulation platform is designed as Figure 2. The signal source is developed by the STM32 MCU and CMX7042 DSP, which produces AIS baseband signal; the Aglient 8920A will modulate the baseband into AIS working frequency in setting field strength; the other 3 8920A will produce the interference signal; all the signal would be combined and sent into the AIS receiver, AIS basestation SAAB R40; and the software will do the statics on how many packages have been missed.
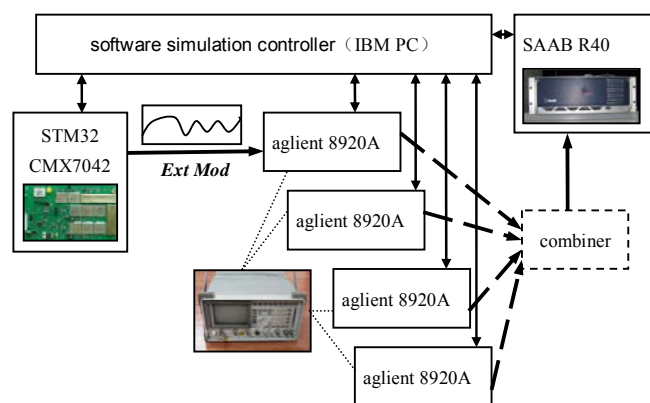

Figure 2. The real hardware-in-loop AIS simulation platform

With the help of the platform, we found that, the relationship between field strength and PER would be decribed as equation 1,

$$y = \frac{2.764 \times 10^{-3} \cdot x'^2 + 1.863 \times 10'^{-2} \cdot x' + 2.821 \times 10^{-2}}{7.532 \times 10^{-3} \cdot x'^2 + 1.548 \times 10^{-1} \cdot x' + 1} \quad (1)$$

where,

$$x' = x + 99,$$

The x stands for the field strength, and the y stands for the PER.

3 FIELD STRENGTH ESTIMATION

3.1 *Ray tracking model*

After the discussion about the relationship between field strength and PER, the filed strength prediction becomes the problem. When in the complex environment, the ray tracking model is a very high efficient tool.

There are three conditions in wireless signal field strength prorogation, which are direct waves, diffractions, and reflections. The multiply will be the final field strength. According to this, the ray tracking method aims to do the exhaustive calculations about direct wave, diffractions, and reflections, and set up attenuation algorithmic model for each condition, to get the real field strength of test spot.

In fact, all the wireless signals propagate under the rule of Maxwell's equations. But the solution to the Maxwell's equation is very difficult to get in practical applications, as the wavelength, paths will cause heavy computations. To simplify the equations, it is required that the wavelength should be far less than the size of barriers in the ray tracking method, and we can assume that the wireless signals' wavelength are close to 0 and the mediums are homogeneous, and ignore most of the electromagnetic wave characteristics. Therefore, the field strength will be shown as below.

$$\vec{E} = \vec{E}_0 e^{-jk\varphi} \tag{2}$$

$$\vec{H} = \vec{H}_0 e^{-jk\varphi} \tag{3}$$

where:

$k = 2\pi / \lambda$, Vacuum propagation coefficient

$\vec{E}_0 = \vec{E}_0(x, y, z)$, Spatial position real function

$\vec{H}_0 = \vec{H}_0(x, y, z)$, Spatial position real function

The $\vec{E}_0$, $\vec{H}_0$ and $k \cdot \varphi$ change with the shaft direction gradually, and the wavelength is assumed to be 0, so the change in the cross-section is negligible.

Under the assumption, it is reasonable to analyze the wireless wave reflections and infractions with the geometrical optics. When all the propagation paths turn to be known, the field strength will be the multiply of the $\vec{E}$. The reflections and diffractions will be discussed below.

3.2 *Reflection model*

On the surface of perfect medium, there is no loss in the wireless signal reflections. When the signal is propagated to the boundary of different mediums, the reflection and refraction will appear. In Figure 3., the full line stands for a boundary, the signal is transmitted from the point O, and the incident of angle is θ, the reflection angle is θR, refraction angle is θr, and the dotted line stands for the spreading of field strength.
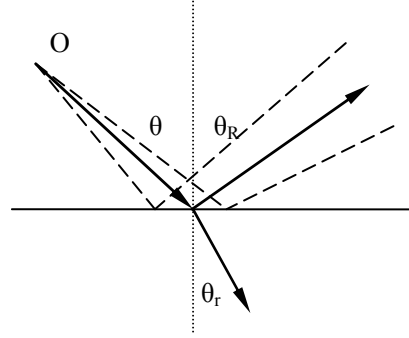

Figure 3. The reflection and refraction

In the reflection angle θR, the variable R will be the key to solve the field strength attenuation, where:

$$R_\perp = \frac{\cos\theta - \sqrt{\varepsilon_r - \sin^2\theta}}{\cos\theta + \sqrt{\varepsilon_r - \sin^2\theta}} \cdot \eta \tag{4}$$

$$R_\parallel = \frac{\varepsilon_r \cos\theta - \sqrt{\varepsilon_r - \sin^2\theta}}{\varepsilon_r \cos\theta + \sqrt{\varepsilon_r - \sin^2\theta}} \cdot \eta \tag{5}$$

ε_r, Relative dielectric constant

η, Reflection efficiency.

In the reflection, there will be some energy consumed by the mediums surface. For AIS, it will be the concrete; we use η to stand for the energy rate that can be reflected.

3.3 *Diffraction model*

The typical diffraction will be shown as below in Figure 4. The wireless signal will propagate to an intersection of two edges, 0 and n. The incident angle is α_1, the reflection angel is α_2, and the diffraction will spread from the intersection.
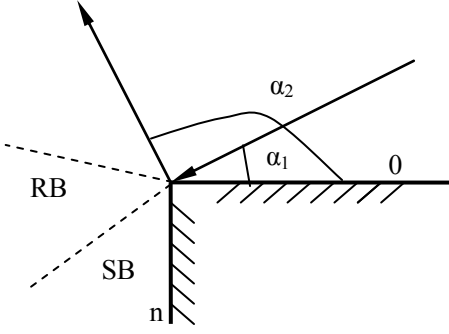
Figure 4. Diffraction

Comparing with the reflections, the diffraction is much more complex, and the analytic geometry is unable to describe. By now, the UTD theory is the only way to make the analysis, the simplification is listed as below. It is necessary to introduce the transition function $f(x)$ to describe the gradual change of the diffraction wireless signal, and use R variable to describe two different edges. According to the equations (4) and (5), there are two value of R when parallel or vertical.

The diffraction parameter D can be calculated by the heuristic equation below:

$$D = [D^{(1)} + R_0 R_n D^{(2)} + R_0 D^{(3)} + R_n D^{(4)}] \cdot \eta \tag{6}$$

η is the same meaning as the reflection. Transition function is shown as follows.

$$D^{(i)} = \frac{-e^{-j\pi/4}}{2n\sqrt{2\pi k}} ctg\gamma^{(i)} F(2k\ln^2 \sin 2\gamma^{(i)})$$

where:

$$\gamma^{(1)} = [\pi - (\alpha_2 - \alpha_1)]/2n$$

$$\gamma^{(2)} = [\pi + (\alpha_2 - \alpha_1)]/2n$$

$$\gamma^{(3)} = [\pi - (\alpha_2 + \alpha_1)]/2n$$

$$\gamma^{(4)} = [\pi + (\alpha_2 + \alpha_1)]/2n$$

$$F(X) = 2j\sqrt{X}\exp(jX)\int_{\sqrt{X}}^{\infty}\exp(-j\tau^2)d\tau \quad ,$$

3.4 *Field strength estimation model*

Based on the equations (2) and (3), it is easy to set up the estimation model to the AIS signal field strength when we know all the propagation paths, reflection parameter R and diffraction parameter D (Hao Ruijing et al. 2007).

Direct propagation,

$$E_{LOS} = E_0 \frac{e^{-jkd}}{d} \tag{7}$$

Reflection,

$$E_R = E_0 R \frac{e^{-jk(s_1+s_2)}}{s_1 + s_2} \tag{8}$$

Diffraction,

$$E_D = \frac{E_0}{s_1} D \sqrt{\frac{s_1}{s_2(s_1+s_2)}} e^{-jk(s_1+s_2)} \tag{9}$$

where:

$k = 2\pi/\lambda$ Vacuum propagation coefficient

E0 the origin transmit power level,

d direct propagation path distance,

s_1 start point to reflections or diffractions point distance

s_2 reflections or diffractions point to receive point distance,

R reflections parameter, according to (4) or (5)

D diffractions parameter, according to (6)

when the propagation includes more than one path, it needs to use the equations above to do the summation, just as equation (10).

$$E_{total} = \sum_i E_i \tag{10}$$

The path loss will be solved as equation (11)

$$L = 20\lg(\frac{\lambda}{4\pi G_t G_r} \frac{|E_{total}|}{|E_0|}) \tag{11}$$

where:

G_r Receive antenna gain

G_t Transmit antenna gain

λ Wavelength

In fact, the wireless signal will attenuate markedly in each reflection and diffraction. Therefore, it is logical to ignore the signals which have reflected or diffracted more than specific times, to make the calculation much easier.

3.5 *Ray Tracking Model*

Due to the massive calculated amount, the ray tracking is considered to be only suitable for the field strength estimation in small area, such as the GSM, CDMA, and WIFI. In the inland rivers, the situation seems to be much more complex, all the factors on the land would take influence on the propagation of wireless signal, the high buildings, the woods, the mountains. It is impossible to exhaust all the factors to

do the analysis, and the simplification is necessary. Luckily, most of the factors above take very tiny effect ion on the signal, the simplifications are feasible.
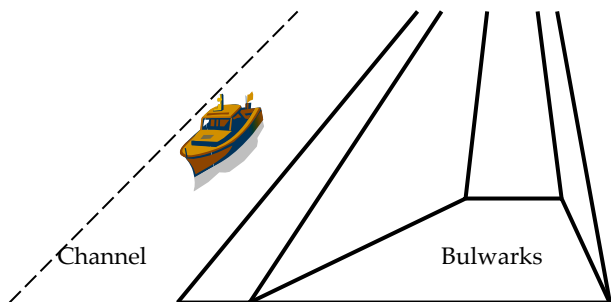

Figure 5. Inland Rivers

The AIS is running on the frequency 161.975MHZ and 162.025MHZ, the wavelength is about 1.852 meters. The chief principle of ray tracking is that, the signal wavelength must be far less than the size of barriers, so, all the matters which are not small than the limited size could be ignored. Besides that, due to the bulwarks and shelter forests, the AIS signal is very hard to escape from the channel and most the spread signal would attenuate to very low level. Just like the figure 5, in most cases, the top of the AIS targets are below the top of the bulwarks. Even a small part of the signal propagate out of the bulwarks, they would be consumed by the shelter woods.

So, it is reasonable to do the simplification, which we assume all the propagations are running in the rivers, just between the bulwarks. The main barriers in the channel would be the bridges, bulwarks, sandbars, levees, docks, anchor piles, not include the buoys whose size are just near to the wavelength of AIS signal.

As the situation in Figure 6, the signal propagation between A and B in some inland river channel has a lot of paths. The banks are just like the mirrors, the edge K would form A' image of A, and the K1 and K2 edges would form B' and B'' images of B, the A' and B', B'' is reachable, so there are 2 different paths by reflection with the help of K, K1, K2. The diffraction is similar to this. With all the equations above and accumulate all the paths, the prediction of field strength became possible.
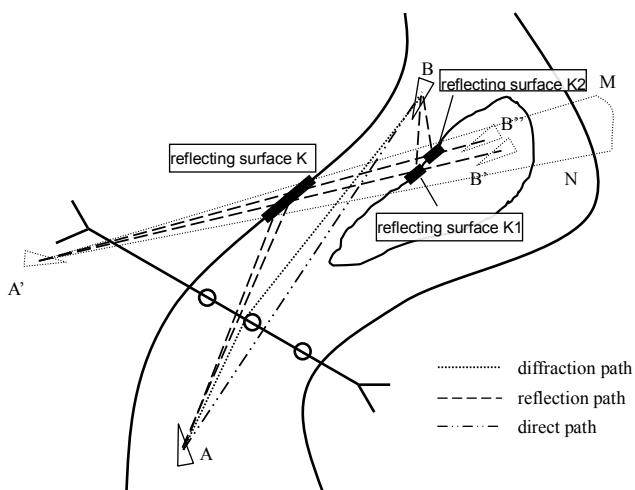

Figure 6. The 2 dimensional ray tracking

4 PER ESTIMATION AND RESULT

Based on the 2 dimensional ray tracking, the 3 dimensional ray tracking is also available, as the Figure 5, between A and B, the propagation paths would be A to C, then B, also A to E, then B. All we should do is exhausting all the paths in define channel.

The A was setting to transmitting at 1W, and the distance between A and B is 4.7 km, the testing time was 6:00 to 18:00, did the statics on every 1 hour, and the weather is sunny, foggy in the morning.
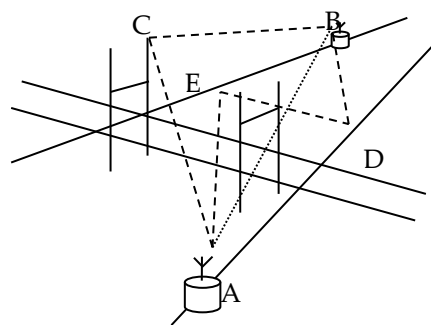

Figure 6. a dimensions structure of the field testing area

The Figure 6 shows a dimensions structure of the field testing area. And the A point field testing is shown in Figure 6. In 12 hours testing, the PER prediction and test result are shown in Table 1.

Table 1. The PER prediction and test result

Time (h)	Test (%)
1st	45.8
2nd	44.2
3rd	37.2
4th	27.2
5th	27.2
6th	26.5
7th	28.5
8th	26.0
9th	25.1
10th	29.0
11th	21.9
12th	21.0
Estimation	26.1

In the testing, we could infer that, in the good weather, after the foggy, the estimation is very close to the test value.

5 CONCLUSION

The AIS is spreading in the inland rivers, and become an essential part of modern maritime management, the performance of AIS is an inevitable problem. The hardware-in-loop simulation shows the relationship between PER and field strength, meanwhile the three dimension ray tracking mode will calculate the attenuation, so the PER estimation become possible, and also been proved. In the further study, the ray tracking model needs to be improve to adapt the weather changing.

REFERENCES

K. Naus, A. Makar, J. Apanowicz. Usage AIS Data for Analyzing Ship's Motion Intensity. TransNav, the International Journal on Marine Navigation and Safety of Sea Transportation, 2007, 1(3): 237-242.

Yan Xinping, MA Feng. Key Technology of Collecting Traffic Flow on the Yangtze River in Real-Time. Navigation of China, 2010, 6(33):41-45.

Tao Limin, XU Changru. Study of the AIS Netting. Marine Technology, 2004(4) : 31-33.

Wang Feizhou.Comprehensive Assessment of AIS Performance. Navigation of China, 2001,(1) : 14-17.

Ma Feng, Yan Xingping, Chu Xiumin, He Runtian. Correlation between signal failure and field strength in automatic identify system. Journal of Dalian Maritime University, 2011,3:111-115.

Chu Xiumin，Xu Haichao, Wan Jian, Song Chengguo. Parsing Shipborne AIS Messages Based on Multithreading，Navaigation China, 2011(2):19:23；

Zhang Fan，chu，xiumin. The Design and Development of AIS System Based on ECDIS, Proceedings of 1st International Conference on Transportation Information and Safety，2011(6).

J.F.Vesecky, K.E.Laws, J.D.Paduan: Using HF surface wave radar and the ship Automatic Identification System (AIS) to monitor coastal vessels. Geo-science and Remote Sensing Symposium, Proceedings of 2009 IEEE International IGARSS 2009: 761 - 764.

K.Hasegawa, K.Hata, K.Niwa, J.Fukuto: Transmission evaluation of Ship-borne Automatic Identification System (AIS) in congested waterways. ITS Telecommunications 8th International Conference, Japan, 2008: 18 – 23.

Lin Changchuan, Dong Fang, Le Jie, Wang Gaoyao. AIS System and the Applications at the Harbor Traffic Management. Proceedings of 4th International Conference on Wireless Communications, Networking and Mobile Computing. 2008: 1.

Dzvonkovskaya A, Rohling H. HF Radar Performance Analysis Based on AIS Ship Information. Page:1239-1244.

Grasso R, Mirra S, Baldacci A, Horstmann J, Coffin M, Jarvis M. Performance assessment of a mathematical morphology ship detection algorithm for SAR images through comparison with AIS data, 2009:602-607.

Hao Ruichang, HAO Ruidong, YANG Jian. Research on capacity planning of GSM-R radio network. Journal of Chongqing University of Posts and Telecommunications (Natural Science), 2007,19(2) : 177-180.