논문 13-38C-03-07
한국통신학회논문지 '13-03 Vol.38C No.03
http://dx.doi.org/10.7840/kics.2013.38C.3.271

해상 선박-육상 통신시스템에서 선박의 흔들림 효과 상쇄방식 성능 분석

케샤브 투샤•, 윤 석 호*, 이 성 로°

Compensating the Effect of Ship Rocking in Maritime Ship-to-Shore Communication

Tushar Keshav•, Seokho Yoon*, Seong Ro Lee°

요 약

본 논문에서는 해상 무선 통신에서 선박의 흔들림으로 인한 신호의 편차문제를 해결하기 위한 새로운 접근방법을 제안하였고, 이를 위해 송신기는 육상에 있고, 수신기는 선박에 위치한 선박과 육상의 통신 시나리오를 가정하였다. 선박은 파도와 바람의 영향으로 인한 해양의 환경 때문에 안정적이지 못하고, 지속적으로 흔들리게 되는데, 이러한 선박의 흔들림은 선박에 위치한 안테나의 흔들림을 유발하여 신호의 수신을 불안정하게 만든다. 여기서, 우리는 신호가 높은 비트 에러율을 발생 수신기에서 상쇄되는 것을 예측할 수 있는데, 이러한 문제를 해결하기 위해 MIMO기술을 사용하여 해결하였다. 본 논문에서 여러 송신 안테나를 사용하는 빔포밍 기술을 구현할 것을 제안하였으며, 제안 방법에 대한 기술의 구현은 강건한 해상 통신 네트워크를 구성할 수 있다.

Key words : Antenna swaying, Beamforming, Maritime, Ship Rocking, Signal variation

Abstract

A novel approach to solve signal variation due to ship rocking in maritime wireless communication is introduced. We assume a ship-to-shore based communication scenario, where the transmitter is on shore and the receiver on the ship. Due to the ocean conditions, such as the presence of waves and wind etc. the ship is not stable and constantly experiences some form of rocking motion. This rocking motion causes the antenna on the ship to sway, creating instability in the signal reception. We envisage that the signal is offset at the receiver incurring high Bit Error Rate. This paper is to investigate and counter this problem by using Multiple-input Multiple-output (MIMO) technique. We propose to implement beamforming technique with multiple transmit antennas. The implementation of this proposed method crafts a robust maritime communication network.

Ⅰ. Introduction

The deployment of a wire-line infrastructure over the maritime environment is unfeasible. As a result, applying an appropriate wireless access technology into the maritime area to extend the lucrative terrestrial network coverage at an acceptable cost has become highly attractive. In a maritime wireless communication environment, the channel state or quality over a communication

※ 이 논문은 2012년도 정부(교육과학기술부)의 재원으로 한국연구재단의 지원을 받아 수행된 연구임(No.2011-0029321)
※ 본 연구는 지식경제부 및 정보통신산업진흥원의 대학 IT연구센터 지원사업의 연구결과로 수행되었음(NIPA-2013-H0301-13-2005)
◆ 주저자 : 목포대학교 전자공학과, keshav.tushar@gmail.com, 학생회원
° 교신저자 : 목포대학교 정보전자공학과, srlee@mokpo.ac.kr, 정회원
* 성균관대학교 정보통신공학부, syoon@skku.edu, 종신회원
논문번호 : KICS2013-01-020, 접수일자 : 2013년 1월 14일, 최종논문접수일자 : 2013년 3월 8일

link is affected by many factors[1,2]. Optimization of the wireless communication system has become critical with the rapid growth of mobile communication services and emerging broadband mobile internet access services. There is an enormous need of high-speed and low cost communication at sea as that on land[3].

However, we face some major obstacles in transmitting wireless signals over water. It should be noted that the characteristics of the wireless communication in maritime are different from that over the land, due to sea surface reflections and the ships properties, such as, its movement and position in the marine environment. Wireless signal propagation analysis in marine environment shows that signals are subject to fading[4]. This is a problem because links experiencing such fading can degrade in quality or fail altogether when the fade margin is insufficient. Moreover, wireless transmission over the open sea experiences stronger signal interference compared to the terrestrial communication systems. On the other hand, the receiver which is located on the ship is not stable and constantly experiences some form of rocking motion. This rocking motion causes the antenna on the ship to sway, creating instability in the received signal.

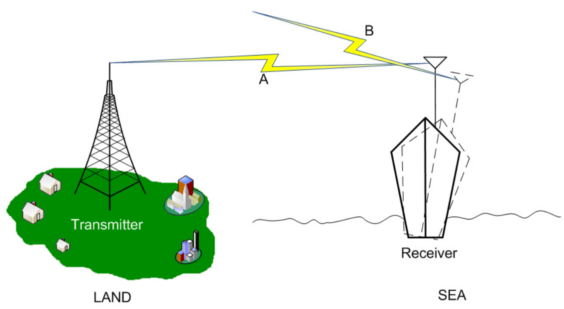

Fig. 1. signal variation caused by ship rocking

We assume a ship-to-shore based communication scenario, where the transmitter is on the shore and the receiver on the ship. If the ship is perfectly stationary, the receiver will have a constant signal strength received because its antenna alignment with the transmitter's antenna remains the same. However, when the ship starts rocking, the antenna alignment between Transmitter and Receiver is dislocated and this causes changes in the received signal strength, since transmit antenna is pointing to A and receive antenna is pointing to B [5]. The scenario is illustrated in figure 1.

To solve the problem, we need to determine the root cause of the ship rocking for wireless transmission over the sea. The main reasons are: the receiver moves up and down along the sea surface in a periodical manner (altitude changes) and the swaying motion (changes in orientation). These movements translate to the receive antenna on the ship. There are many approaches to solve this problem; First, the antenna orientation and type can be changed. Second, a mathematical model can be made to understand the sea state and the effect of ocean waves on the received signal. Furthermore, signal offset can be compensated which improves the Bit Error Rate (BER) and the overall system performance. According to J. Joe et al. [6] Boat rocking contributes to a very large received signal variation. This was verified by conducting an experiment to measure the standard deviation of the received signal.

In this paper we present a novel approach to solve the effect of ship rocking which causes signal variation at the receiver. We propose to implement transmit signal beamforming technique with multiple antennas at the transmitter. Transmit beamforming is an emerging technique to considerably improve the performance of multiple-antenna transmission. We begin by analyzing the ship rocking using the sea state conditions and the extent of signal offset caused by each sea state. A comparison will be made by plotting the BER curve for each sea-state condition. Furthermore, we apply transmit beamforming and note the system performance improvement.

The paper is organized as follows: In Section II, we present a brief overview on ocean waves. In Section III, six degree of freedom or in other words motions of the ship are discussed. In Section IV, we analyze the ship rocking problem. In Section V, we introduce the transmit beamforming technique. Section VI, gives the system description, followed by the simulation and results in Section VII. And finally we conclude in Section VIII.

Ⅱ. Ocean Wave Analysis

Ocean waves are dependent upon the wind. The more the wind, the bigger the waves. These ocean waves are related to the motion of ship in the sea. Ships tend to have some form of rocking motion, which affects the communication link between the ship and the shore[7]. Various idealized spectra are used to answer the question in oceanography and ocean engineering. St. Denis and Pierson introduced the exciting new theory of sea-wave behavior and its effect on ships[8]. They assumed that if the wind blew steadily for a long time over a large area, the waves would come into equilibrium with the wind. This is the concept of a fully developed sea[9].

The ocean wave is often depicted as a typical sine wave movement pattern; however, by experiments the wave shape is described as a Trochoid[10], whose properties are known to be similar to that of sea waves. The roughness of the sea surface is measured by so called sea states, which is characterized by parameters of significant sea wave height, average sea wave length, and average sea wave period. Significant sea wave height is the mean wave height of the one-third highest wave[11,12]. In this paper, since we do not have any real time data, we use the sea state data from Pierson – Moskowitz sea spectrum[13]. The Pierson – Moskowitz spectra was developed from measurements in 1964. Higher levels of sea state indicate large wave heights and severe sea state conditions.

On the other hand, due to the reflective nature of sea surface, the reflected component of the signal is influenced by the sea state conditions. It is expected that in calm sea conditions (sea state 1 through 4) the signal offset is negligible. However, as the significant wave heights increase the severity of the sea conditions also change and the signal offset at the receiver is probable to worsen, since the incoming wavefronts will be scattered due to rough sea conditions.

Ⅲ. Ship Motions

The motions of a ship can be described using a three dimensional reference frame where six quantities can be measured, which are; rotations about each of the axes and translations in the direction of each of the axes. These motions are coupled and therefore not easily interpreted when looking for insight into the behavior of the ship. The common terminology used are: Surge – translation along x-axis, Sway – translation along y-axis, Heave – translation along z-axis, Roll – rotation along the x-axis, Pitch – rotation along the y-axis, and Yaw – rotation along the z-axis. These motions are depicted in figure 2. These motions are generated by the typical ocean waves which translate to the motion of the antenna on the ship.

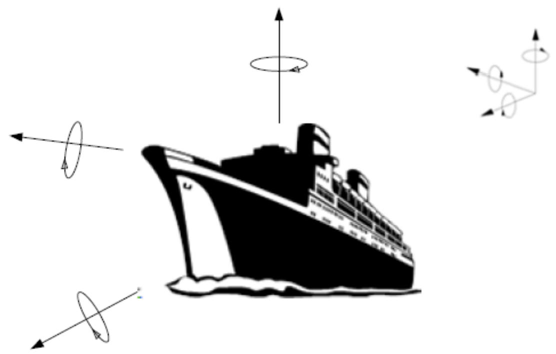

Fig. 2. ship motions

Ⅳ. Ship Rocking Analysis

Ships on the sea surface will have different orientation at the same time if their locations are different. Which means both time and position affect a ship's orientation in a marine environment. For instance, taking two ships into account, A and A'. When A rises up, A' is in trough. Figure 3 illustrates the effect on the receiver due to waves. At time t, the receiver rises up (A), at time $t+1$, the receiver moves down (A'). If the ship is anchored, the orientation would still change in time even though the position of the ship does not change.

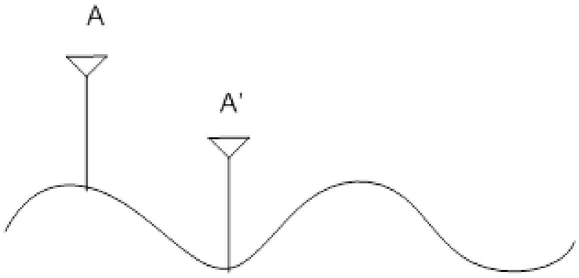

Fig. 3. receiver unit movement on ocean surface

It is presumed that ocean waves follow the basic wave equation $c = f\lambda$. The velocity of a travelling wave on the sea is wavelength dependent. The wave speed is given by

$$v = \sqrt{\frac{g\lambda}{2\pi} tanh(2\pi \frac{d}{\lambda})} \qquad (1)$$

Where λ is the wavelength, d is the sea depth and g is the acceleration of gravity.

The estimate of the degree of tilt of the ship is made using the travelling wave equations. The tilt of the ship was computed using the magnitude of the wave at the front and rear ends of the ship. The difference of the magnitudes gave the angle of the tilt, θ. It should be noted that this angle θ, depends not only on the severity of the waves (sea states) but also on the size of the ship. A ship larger than the wavelength will experience less rocking compared to the ship that is smaller than the wave. The angle of the tilt θ, is given by:

$$\theta = \tan^{-1}\left(\frac{Hy(front) - Hy(rear)}{Dx(front) - Dx(rear)}\right) \qquad (2)$$

The ships effective height $Hy(front)$ and $Hy(rear)$ is given by $k - a \times \cos(d/\lambda - t/T)$, where k and a are constants at time, t when the ship is d distance from the origin. The constants determine the amplitude of the waves where, $k = \lambda/2\pi$ and $a = H/2$. Wavelength λ, and the period T, are the determining factors of the steepness of the waves. The values of the parameters λ, T and H are taken as average wavelength, average wave period and significant wave height from Pierson-Moskowitz Sea Spectrum[13] for specific sea states.

The ships front and the back parts $Dx(front)$ and $Dx(rear)$ are laid out in the direction of the wave. This is illustrated in figure 2. The $Dx(front)$ and $Dx(rear)$ are calculated as follows: $Dx(front) = d + (W\cos(\pi/2 - \alpha))/2$ and $Dx(rear) = d - (W\cos(\pi/2 - \alpha))/2$ where W is the width of the ship and α is the angle between the direction of the ship and the wave.

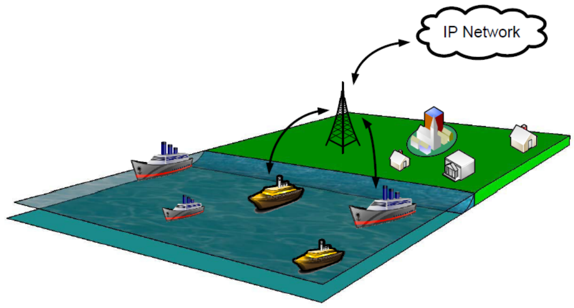

Fig. 4. Ship-to-Shore communication scenario

V. Transmit Beamforming

Multiple antennas can be used to transmit the same signal from each antenna element such that the effect is to focus the transmitted beam in the direction of the receiver and away from interference. Beamforming can provide significant improvement in signal strength, quality, and increase capacity and reliability. It is a powerful technique which increases the link signal-to-noise ratio (SNR) through focusing the energy into desired directions[14]. Transmit beamforming is a simple multiple-antenna transmission technique which exploits channel knowledge at the transmitter and receiver. It has become an emerging technique to considerably improve the performance of MISO system[15]. Typically, it works on the principle that signals sent on each transmit antenna can be combined constructively at the receiver. This is achieved by manipulating the phases of the transmitted signals to improve

Table 1. sea state parameters[13]

Sea State	Wind speed (knots)	Average wave period (sec)	Significant wave height (m)	Average wave length (m)
4	18	5	1.83	24.1
5	21	5.5	2.4	32
6	27	7.5	4.3	56.1
7	37	10	7.62	100.13
8	49	13	13.72	180.1

directivity. In this paper, we implement two transmit, single receive (2x1) antenna configuration to compensate the signal offset that occurs due to ship rocking.

Ⅵ. System Description

A generic maritime ship-to-shore communication is considered. Figure 4 shows the system model that will be simulated in this work. We assume the ships to be arbitrarily located in a marine environment and are connected to the wireless network via the base station on land. We envisage that signals are offset at the receiver located on the ship. This accusation is proofed by plotting a BER graph showing the effect of ship rocking on the signal performance in different sea state conditions. The degree of ship tilt occurred will be compared with different sea state using the Pierson-Moskowitz Sea Spectrum[13] since we don't have real time data. Table 1 gives the parameters for each sea state that will be simulated in this work. We consider sea state 4 through 8 in our scenario.

Ⅶ. Simulation & Results

The first part of the simulation results investigate the effect of ship rocking on the BER performance of the system. We considered 5 sea state levels (sea state 4 through sea state 8) on two different dimensions of ships (small ship and big ship) in our simulation, to better understand the rocking effect and its relation to the BER. Sea States 1, 2 and 3 were not considered since they did not make much difference to the signal offset. Sea state parameters used are shown in Table 1. The smaller ships dimension was assumed to be 40 meters in length, 6 meters wide and 7 meters in height. The bigger ships dimension was assumed to be 60 meters in length, 15 meters in width and 20 meters in height. The transmission frequency was taken as 2.3GHz.

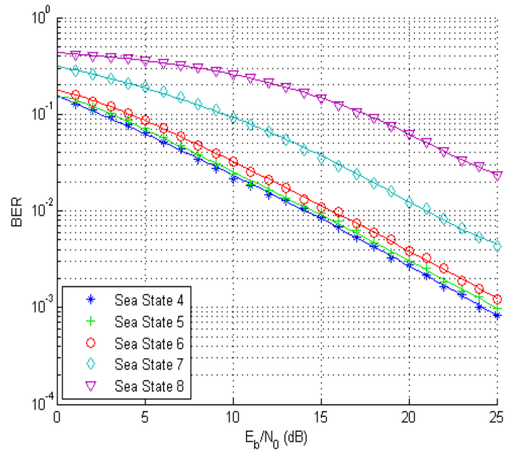

Fig. 5. simulation results for the effect of ship rocking on the BER performance with different sea state conditions for small sized ship

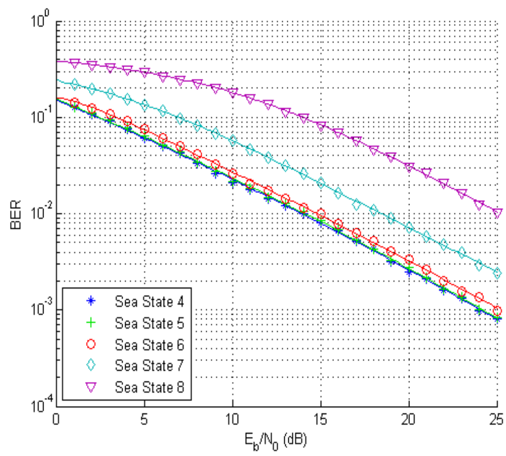

Fig. 6. simulation results for the effect of ship rocking on the BER performance with different sea state conditions for a big sized ship

The tilt angle of the ship was calculated and simulated in the MATLAB software. Figure 5 is the results obtained for BER degradation due to ship rocking for small ship and figure 6 shows the BER degradation for the larger ship.

It is evident from the BER plots that as the sea state increased (more severe sea conditions) the ship rocking increased. The size of the ship was also a determining factor of the rocking effect. It can be noted that the BER degradation is much higher for a smaller ship. In other words, a larger ship is able to sustain some degree of rocking in the sea.

In the latter part, we illustrate the novel method to solve the effect of ship rocking. As stated earlier, we will implement transmit beamforming to compensate the signal offset caused by ship rocking. From our former results, it is apparent that ship rocking has considerable effect in BER performance of a communication link.

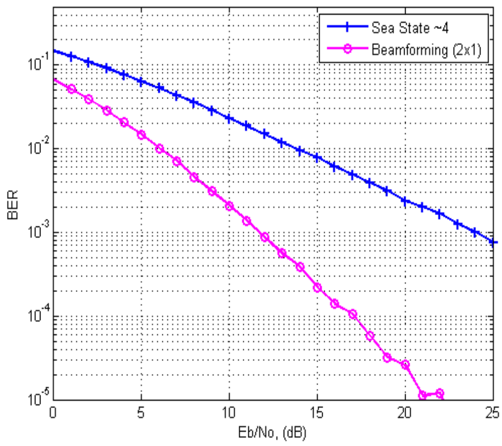

Fig. 7. BER performance for transmit beamforming

Two transmit, single receive antenna configuration is simulated in this work. The BER improvement is noted. Figure 7 plots the results obtained for transmit beamforming using MATLAB software. The upper curve shows the BER for sea state condition (no beamforming applied) and the other curve shows the impact on BER performance after applying beamforming. It can be noted that a considerable improvement in BER performance occurs after applying transmit beamforming.

Ⅷ. Conclusion

Effect of ship rocking in maritime ship-to-shore communication is presented. In a marine environment the ship is not stable and constantly experiences some form of rocking motion. This rocking motion translates to the swaying of the antenna on the ship. In this paper, we investigated the extent of BER degradation due to ship rocking in different sea state conditions. Results obtained confirm our accusation on signal offset at the receiver due to ship rocking. It was also found out that the rocking effect depends on the size of the ship. The smaller sized ship was more unstable due to rocking effect whereas a much larger sized ship was quite stable. This was evident in the BER performance simulation of the system. Furthermore, we opt to solve this problem by implementing transmit beamforming technique. Transmit beamforming is a powerful technique to focus all energy in one direction. We were able to achieve a much lower BER after implementing transmit beamforming in our simulation. Future work may include conducting experiments to obtain real-time sea state data for more accurate real time scenarios.

References

[1] J. G. Andrews, A. Ghosh, and R. Muhamed, *Fundamentals of WiMAX: understanding broadband wireless networking*, Upper Saddle River, NJ: Prentice Hall, 2007.

[2] W. Hubert, M. Y. L. Roux, M. Ney, and A. Flamand, "Impact of ship motion on maritime radio links", *Int. J. Antennas and Propagation*, vol. 2012, pp. 1-6, Nov. 2012.

[3] L. Mu, R. Kumar, and A. Prinz, "An integrated wireless communication architecture for maritime sector," in *Proc. Int. Conf. on Multiple access commun 2011 (MACOM 2011)*, pp. 193-205, Trento, Italy, Sep. 2011.

[4] T. Keshav, S. Lee, "A study on the WiMAX

propagation models for maritime radio links," in *Proc. KICS Conf. Commun.* 2012, vol 48, pp. 210-211, Jeju Island, Korea, June 2012.
[5] ITU, "Maritime broadband wireless mesh network," ITU-R. M.2202, Geneva, 2011.
[6] J. Joe, S. K. Hazra, S. H. Toh, W. M. Tan and J. Shankar, "5.8GHz fixed WiMAX performance in a seaport environment," in *Proc*. Veh. Technology. Conf. (VTC-2007), pp. 879-883, Sep. 2007.
[7] S. K. Lee, H. Choi, and S. Surendran, "Experimental studies on the slowly varying drift motion of a berthed container ship model," *J. Ocean Eng.*, vol. 33, pp. 2454-2465, Nov. 2010.
[8] M. S. Denis and W. J. Pierson Jr, "On the motion of ships in confused seas," New York Univ., Nov. 1953.
[9] M. K. Ochi, *Ocean waves: The stochastic approach*, Cambridge University Press, 1998.
[10] Mayo and Ned, *Ocean waves-their energy and power*, Physics Teacher 35, Sep. 1997.
[11] M-T Zhou and H. Harada, "Cognitive maritime wireless mesh/ad hoc network," *J. Network Computer Applicat.*, vol. 35, no. 2, pp. 518-526, ScienceDirect, 2012.
[12] W. M. Drennam, P. K. Taylor, and M. J. Yelland, "Parameterizing the sea surface roughness," *J. Physical Oceanography*, vol 35, no. 5, pp. 835-848, May 2005.
[13] Pierson-Moskwitz Sea Spectrum, Retrived Nov. 28, 2012, [Online] Available: http://www.syqwestinc.com/support/Sea%20State%20Table.htm
[14] C. Oestges, B. Clerckx, *MIMO wireless communication: From real-world propagation to space-time code design*, Oxford Academic Press, 2007.
[15] P. A. Dighe, K. Mallik, and S. S. Jamuar, "Analysis of transmit-receive diversity in Rayleigh fading," *IEEE Trans. Commun.*, vol. 51, no. 4, pp. 694–703, Apr. 2003.

케샤브 투샤 (Tushar Keshav)

Nov. 2010 BE from University of the South Pacific, Fiji
Sep. 2011~present MS Student, Dept. of Electronics Engineering, University of Mokpo, South Korea.
<Research Area> Wireless Communication, Telematics, Communication System, Mobile Network

윤 석 호 (Seokho Yoon)

1997년 2월 한국과학기술원 전자전산학과 공학사(최우등)
1999년 2월 한국과학기술원 전자전산학과 공학석사
2002년 2월 한국과학기술원 전자전산학과 공학박사
2002년 3월~2002년 6월 MIT 박사후 연구원
2002년 7월~2003년 2월 하버드대학교 박사후 연구원
2003년 3월~현재 성균관대학교 정보통신공학부 전임 강사, 조교수, 부교수
2000년 2월 삼성 휴먼테크 논문대상 동상 수상
2007년 Marquis Who's Who in Asia에 등재
2007년 IEEE 준석학회원
2008년 Marquis Who's Who in World에 등재
2009년 한국통신학회 LG 학술상 수상
<관심분야> 통신 이론, 이동통신, 통계학적 신호처리

이 성 로 (Seong Ro Lee)

1987년 2월 고려대학교 전자공학과 공학사
1990년 2월 한국과학기술원 전기및전자공학과 공학석사
1996년 8월 한국과학기술원 전기및전자공학과 공학박사
1997년 9월~현재 목포대학교 공과대학 정보전자공학과 교수
<관심분야> 디지털통신시스템, 이동 및 위성통신시스템, USN/텔레매틱스응용분야, 임베디드시스템