Maritime Visible Light Communication with Sea Spectrum Models

Hyeongji Kim, Atul Sewaiwar and Yeon-Ho Chung

***Abstract*—** This paper presents a Visible Light Communications (VLC) system concept in maritime environments to overcome the limitations of conventional maritime wireless communication. The proposed concept is a cost effective method of implementation using LED-based lighthouse and beacons. The transmission system presented for shore-to-sea communication considers unique properties of maritime environments where wave height, wind speed, etc. exist. Computer simulations are conducted based on the PM and JS spectrum models with various sea states for analysis. It is found that the JS model outperforms the PM model. The transmission distance of the proposed system is dependent upon the LED power and sea states. It is found to be approximately 1,000m for the sea state 6 of the JS model at a BER of 10^{-3}.

***Keywords*—** Maritime communication, VLC, LEDs, e-Navigation, Pierson-Moskowitz model, JONSWAP model

I. Introduction

International Maritime Organization (IMO) developed e-Navigation for maritime safety and security [1]. It collects maritime data information electronically onboard and enhances berth to berth navigation and related services at sea [1]. Among those communication system projects, two exemplary systems are commonly considered: TRITON and WOP.

TRI-media Telematic Oceanographic Network (TRITON) based on IEEE 802.16 and IEEE 802.16e implemented a mesh network in Singapore for maritime communication using a ship, lighthouse and buoys as communication nodes with the objective to develop a system for high-speed and low-cost maritime communications in narrow water channels and shipping lanes close to the shore [2]. European Space Agency (ESA) also introduced Wired Ocean Project [3]. The intent of this project is to establish, on a commercial basis, cost-effective broadband IP-based communications services to ships. However, the cost is expensive with the use of VSATs.

Moreover, the current maritime wireless communications at sea mainly rely on satellite links that are relatively slow than HF, VHF and expensive Inmarsat. Like on land, sea users also need a high-speed, low-cost maritime wireless communication and special service (Mobile Telemedicine in maritime [4], Container Tracking [5], etc.). Therefore, new technology is needed to improve existing maritime communications.

In this paper, we propose a scheme to overcome the issues in maritime communication with visible light communication (VLC) termed as Maritime VLC (MVLC).

As a maritime network suffers from insufficient dedicated operation spectra, which is more likely in the future due to congested RF bands, VLC is a promising candidate with a vast spectrum, i.e. 10,000 times more than RF. Furthermore, the widespread use of visible light could provide necessary infrastructure, e.g. lighthouse and beacon. Thus, the VLC-based maritime wireless communication can be considered as an attractive technology. Maritime VLC system can support shore-to-ship, ship-to-ship communication without requiring the change of frequency channel.

The rest of this paper is organized as follows. Section II introduces the maritime VLC system together with channel model. Performance analysis and simulation results are presented in Section III. Finally, Section IV shows conclusions drawn from the investigation.

II. System Configuration

A. *Concept of maritime VLC System*

VLC is a communication method using LEDs, where blinking of a LED is used for communication and illumination simultaneously. LED communication offers innovative wireless technologies in terms of communication speed, flexibility, usability and security. LED's can be switched off and switched on faster than we can perceive. This on-off motion can be used to represent 0's and 1's, in other words, digital communication [6]. Unseen by the human eye, this variation is used to carry high -speed data, thereby creating wireless communication network using existing light resources in order to achieve low cost communication.

Maritime environment divides coast and offshore. We propose a VLC based maritime system that covers shore-to-sea communication services. Fig. 1 shows the proposed system in which communication coverage area can be increased at low-cost implementation. The mesh network is formed by neighbouring ships, marine beacons and buoys, and is connected to the terrestrial networks via VLC. The base station consists of power LEDs that provide coverage to a very large area, while sea transceivers (marine beacons, buoys, oil/gas platforms, sea farms) consist of an LED array and photo diodes.

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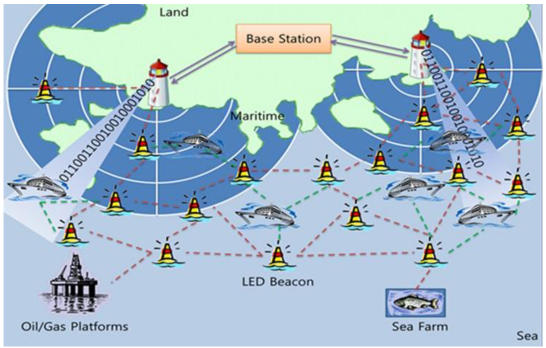


Fig. 1 High- level architecture of maritime VLC network

B. Maritime Channel Modeling

Maritime communication environments have unique property where sea surface movement is usually observed and subsequently periodic degradation exists. If long sea wave period occurs, the communication link may exhibit poor quality, thus causing data retransmission. Therefore, the maritime communication environment is mainly characterized by this sea surface movement, together with radio propagation and Fresnel effect [7].

The most typical mathematical model of sea wave is the renowned Pierson-Moskowitz (PM) power spectral density function [8].

Since the real-time data is not available for simulations, we employed sea state data from PM spectrum model in this study, as it was developed from measurements of various sea parameters. This model is based on the theory of sea behavior assuming that if the wind blew for a long time over a large sea area, the waves would come into equilibrium with the wind.

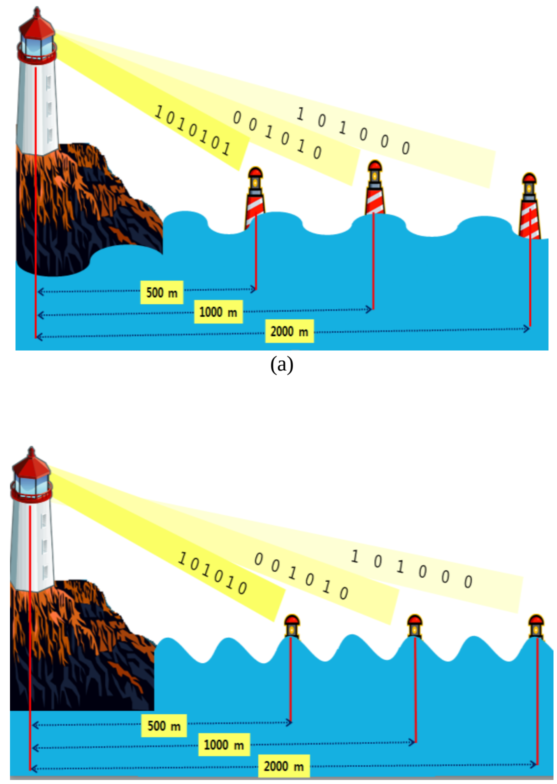
On the other hand, the JONSWAP (JS) model is based on non-linear and wave-wave interactions for very long times and distances [9]. This experimental model is shown to be more realistic.

Table I. Sea state parameters

Sea state	Wind speed		Average wave period	Significant wave height	Average wave length
	(knot)	(m/s)	(sec)	(m)	(m)
4	18	9.26	5	1.83	24.1
5	21	10.8	5.5	2.4	32
6	27	13.89	7.5	4.3	56.1
7	36.5	18.9	10	7.62	100.13
8	43.75	22.5	13	13.72	180.1

Table I shows the sea state parameters [10]. The sea state conditions mentioned in Table I are reflected as a result of reflective nature of sea surface and wave height, which is a measure of roughness of sea parameters. At lower sea states, i.e. state 1 to 4, the sea conditions are mild, and hence the signal distortion is negligible at the receiver. While at higher states, sea conditions are hostile with relatively high waves and rapid moving winds. These would result in scattering of incoming signals, thus causing the signals to be extremely damaged at receiver [11].

Sea surface moves all the time and thus renders link quality unstable. The sea wave movement continuously changes the marine beacon orientation and height, thus changing the marine beacon gain and received signal power. Fig. 2 shows the present maritime channel model under consideration. It consists of base station and maritime transceivers (beacons) placed over the sea.



(a)

(b)

Fig. 2 Maritime channel model: (a) Sea state 4 (b) Sea state 8

III. Simulation Results

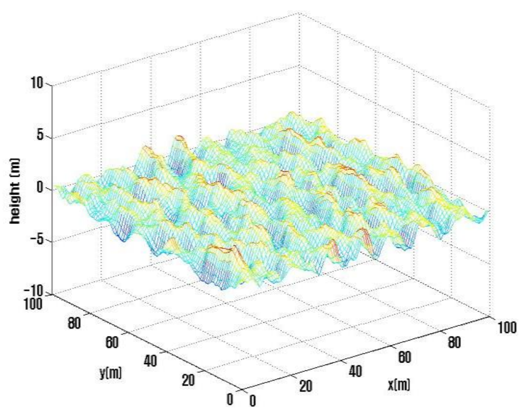
Simulation has been carried out to investigate the link performance for the proposed shore-to-sea maritime VLC system. Performance is evaluated in terms of Bit Error Rate (BER) against Signal to Noise Ratio (SNR) values with respect to distance between base station and beacons. We used the parameters shown in Table II and obtained the BERs for the proposed maritime VLC system. Further, we employed On-Off Keying (OOK) modulation technique for the VLC transmission.

For the simulations, we use the sea state data from PM spectrum. For example, Fig. 3 shows sea surface of the sea state 4, 8 PM spectrum.

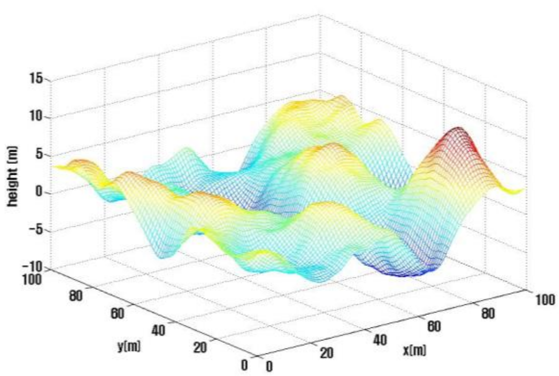
In Line of Sight (LOS) channel, the light from transmitter is directed towards the receiver where we measured SNRs and BERs. The receiving plane is assumed to be 10m x 10m over a beacon (maritime transceiver) as shown in Fig.4. Also, all subsequent analyses in terms of BERs and SNRs were conducted at the sea state 4.

Table II. Parameters of the simulation

Parameters	Values
Transmitted optical power (All LED)	500 W
Detector physical area	9 cm^2
Bit rate	1 Mbps
Channel	Maritime channel
Number LED	100
Field of view	50
Distance between lighthouse and receiver	[100 300 500 1000 1500 2000] m
Refractive index of a lens at receiver	1.5
LED half angle	60°
Receiving plane dimension	10m x 10m



(a)



(b)

Fig. 3 Sea surface from the PM spectrum: (a)Sea state 4 (b) Sea state 8

Figs. 5 and 6 show the performance of the proposed channel model, where transmitter and receiver are separated with the

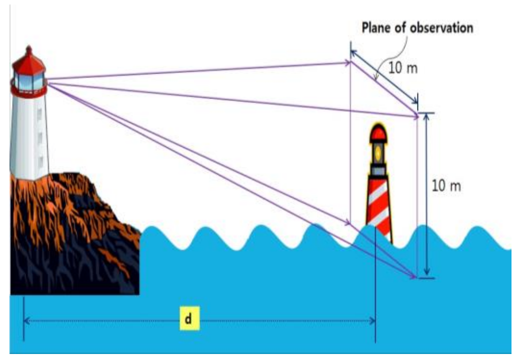


Fig.4 The receiving plane (10m x 10m)

distance of 500m. Figs. 7 and 8 show the performance of the channel between the transmitter and the receiver at the distance of 2000m.

Fig. 9 shows the analysis of the maritime VLC system under the sea state 6 and 8. Overall, the JS model outperforms the PM in terms of BER. The JS model for sea state 6 shows a performance of 10^{-3} at the distance of approximately 1,000m. However, the BER performances at a larger distance between the transmitter and the receiver are poor, thus requiring higher LED power and LOS path.

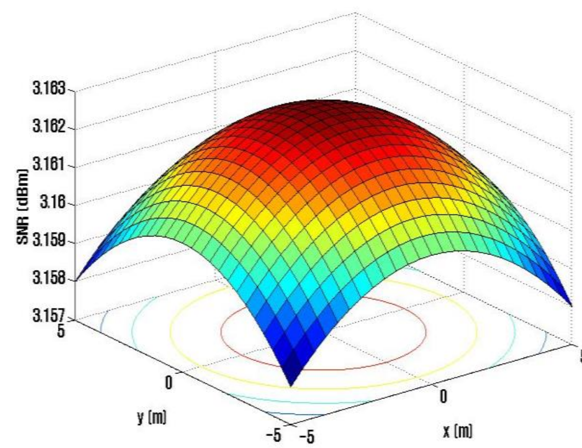


Fig. 5 Simulated maritime channel SNR (500m)

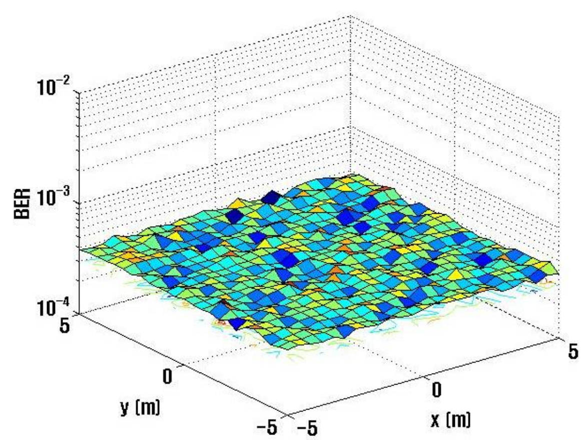


Fig. 6 Simulated maritime channel BER (500m)

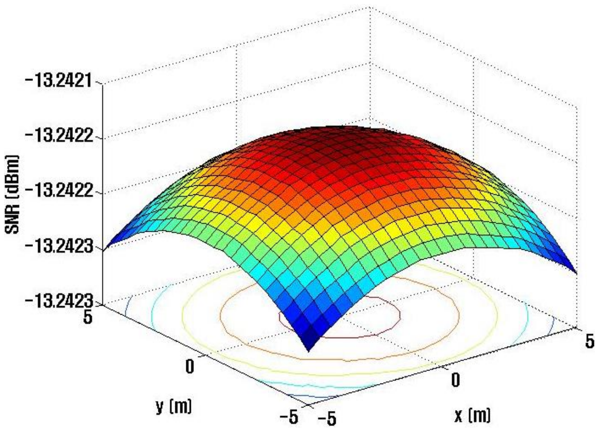


Fig. 7 Simulated maritime channel SNR (2000m)

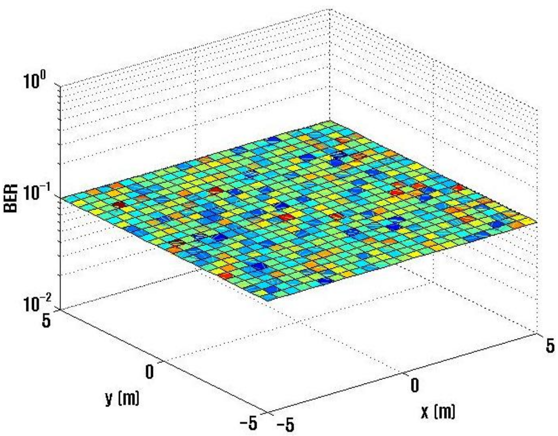


Fig. 8 Simulated maritime channel BER (2000m)

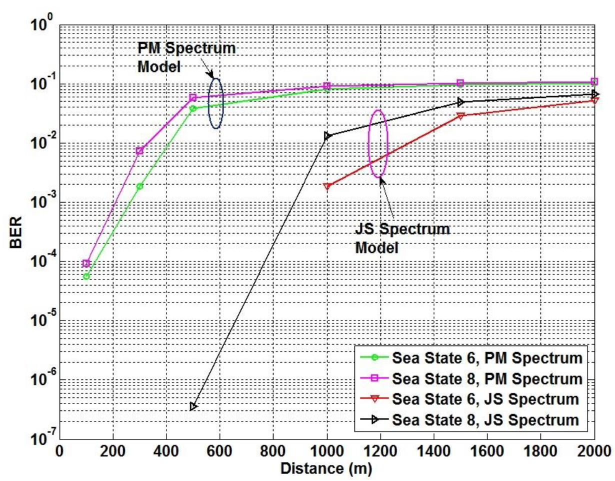


Fig. 9 Performance analysis of the maritime VLC system under sea state conditions

IV. Conclusion

VLC system is proposed for maritime environments and analyzed relative to distance, based on JS and PM sea spectra. The proposed system encompasses visible light transmission using LEDs and photo diodes for the transmission between shore and sea. Recognizing the fact that the existing maritime communication networks have limitations such as a lack of bandwidth and installation of expensive network infrastructure, the proposed maritime VLC can be an attractive candidate for advanced maritime broadband communications for e-Navigation. Performance evaluation has been conducted using the PM and JS models. The performance relative to the sea states varies in terms of distance. It is shown that the JS model appears to be more realistic and produce better performance over a larger distance.

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