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A Comparative Performance Evaluations of SC and MC VLC Systems in Underwater Environments

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Abstract— In this study, comparative performance analyzes of single carrier (SC) and multi carrier (MC) visible light communication (VLC) schemes in underwater optical channel environments are performed. Computer simulation studies are carried out to compare SC and MC VLC communication systems in underwater optical LOS and N-LOS channel environments based on bit error rate (BER) success benchmark. From the acquired outcomes, it is perceived that SC-VLC communication system has approximately 8 dB better performance than MC-VLC communication system in both channel environments.

Keywords: *underwater environment; visible light communications; underwater optical channel; SC-VLC; MC-VLC.*

1. Introduction

High speed communication emerges as a subject that the whole world wants and works on. Visible light communication (VLC) is one of the communication types that are very suitable for use in the underwater environment. It supports long distance communication even if data rates are low at the time of communication (Zeng et al., 2017). Important factors such as the proliferation of human activities in underwater surroundings, oil field exploration, and providing coast security increase the need for robust and high-speed data communication (Arnon et al., 2012). In the underwater environment, when a suitable environment is created, communication can be achieved with high data rates. Data transmission in VLC is achieved by modulating the density of the light emitting diode according to the transmitted input signal. The transmitted signal is transformed and reaches from the optical signal to the electrical signal with the help of a photo diode. The LED used as a transmitter is an important lighting tool and is used optically and wirelessly.

Underwater wireless communication can be provided in different ways. Some of these are radio, optical and acoustic waves. Of these, radio frequency waves weaken significantly in the aquatic environment and limit the transmission range in a very short distance. On the other hand, acoustic waves can help transmission ranges per kilometer, and they are commercially important to underwater modems. However, acoustic waves are insufficient in applications where bandwidth is needed and real-time video transmission due to their low data rate. In addition, the value of optical communication has increased due to the diversification of underwater technology and its data-intensive. It has a stronger transmission compared to acoustic waves (Zeng et al., 2017). Wireless transmitters can be used in visible light sources, as water creates a more transparent spectrum against light in the blue and green bands of the optics. Thus, underwater VLC (UVLC) technology has become a low-cost, economical technology that reaches higher data rates. UVLC is a very interesting technology for long range communication. Tens of Megabit/sec signal speeds, experimental UVLC results exceeding Gigabit/sec were analyzed and reported in laboratory environments (Nakamura et al., 2015; Kong et al., 2017; Shen et al., 2016; Elamassie et al., 2019).

In VLC, the light intensity is modulated by the information signal. A transmission can be performed with blue, red or green colored lasers even with a range of tens of meters. The speeds of the transmitted signals can be shown with data rates between Gbit/s (Kong et al., 2017). Channels have frequency selectivity in the underwater environment. Orthogonal frequency division multiplexing (OFDM) has been considered as an important technique to eliminate the effect of inter symbol interference (ISI) in underwater VLC systems (Elamassie et al., 2019). VLC system adopts intensity modulation and direct detection. Hence, the radiated signals should not be complex and negative (Yeşilkaya et al., 2017). OFDM signaling must be changed accordingly to accommodate this.

In this study, the performance of SC-VLC and MC-VLC systems in underwater optical channel environment is analyzed. SC-VLC and MC-VLC systems are tested using flat fading underwater optical LOS channels and flat fading underwater optical N-LOS channels using bit error rate (BER) success benchmarks. From the acquired outcomes, it is understood that SC-VLC systems are 8 dB better than MC-VLC systems for 1E-4 BER value.

The remaining of the article is planned as following: In Section 2, the SC and MC underwater VLC systems are explained in detail. Computer simulation works in Section 3 are demonstrated. Discussions and remarks are evaluated in the last stage.

2. SC and MC Underwater Visible Light Communication Systems

The transceiver unit scheme of the SC and MC VLC technology operating in the underwater optical channel environment is shown in Figure 1 (Güçlü, 2021).

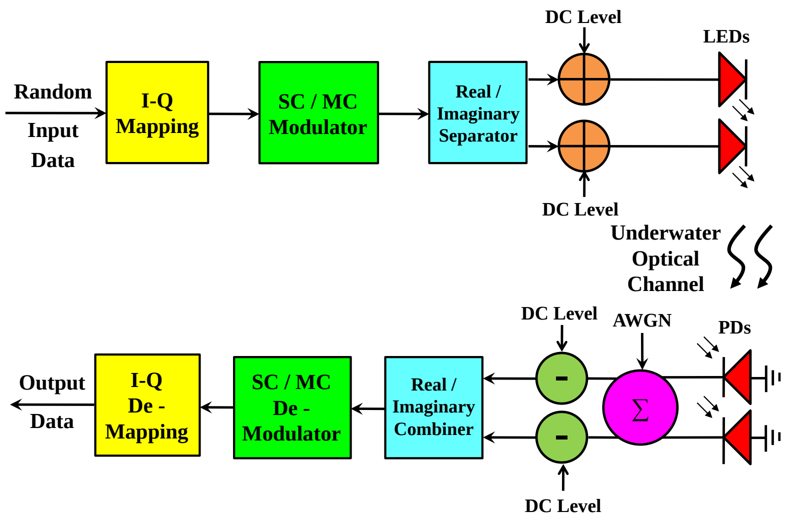

Figure 1. The block scheme of the SC and MC VLC systems in underwater optical channel environments (Güçlü, 2021).

The randomly generated serial input knowledge on the sender part of the SC and MC VLC scheme operating in underwater optical channel environment in Figure 1 are modulated by one of the requested modulation methods in the I-Q Mapping Unit. Then SC and MC information frames are generated in the SC/MC Modulator Unit. Since the intensity modulation/direct detection (IM/DD) scheme is utilized for the sending of knowledge in VLC schemes, the information to be transmitted via the LEDs must be real and positive. SC and MC information packets produced at the output of the SC/MC Modulator Unit are separated into their real and imaginary sections in the Real/Imaginary Separator Unit. Later, as the acquired information are real but bipolar information, as noticed from the unit scheme, DC level is added to both components to make the sent information signals positive. In this work, the DC level is defined such that the smallest value of the transmitted data bits is zero. The acquired real and positive data bits are sent over the multipath underwater optical channel through LEDs and received by photo diodes at the receiver part and are deformed by additive white Gaussian noise (AWGN). By doing the inverse of the procedures on the sender part at the receiver part, a deformed data bit is attained at the output of the Real/Imaginary Combiner Unit. The distorted information signal is corrected using appropriate equalization methods. Then the solved signals at the SC/MC De-Modulator Block output are demodulated in the I-Q De-Mapping Block. Then, utilizing the acquired information at the output, the requested performance criteria can be calculated. In this study, the performance of SC and MC-VLC systems in underwater optical channel environment is compared over the BER criterion.

3. Computer Simulation Studies

The simulation studies of computer are composed of two sections. In the first section, simulations are made on flat fading underwater optical LOS channels and in the second phase on flat fading underwater optical N-LOS channels. SC-VLC and MC-VLC systems using BPSK, 4-QAM and 16-QAM signals are compared in all simulations. OFDM data packets in MC-VLC systems are prepared in accordance with IEEE 802.11a Standard using 64-point FFT.

3.1. Simulation Results of Flat Fading Underwater Optical LOS Channel

In this study of the first phase, achievements of the BER-SNR of SC-VLC and MC-VLC systems in flat fading underwater optic LOS channels are compared. Simulations are made by using the impulse response value of 1.30×10^{-6} from the underwater optical channel impulse response measurements measured in the reference (Miramirkhani et al., 2018; Miramirkhani, 2018) as the flat fading underwater optical LOS channel impulse response. Simulations were obtained via 1000 Monte Carlo loops, utilizing BPSK, 4-QAM and 16-QAM modulated signals with 1000 data packets of related communication systems.

Figure 2 illustrates the evaluation of BER-SNR achievements of BPSK modulated SC and MC-VLC systems for flat fading underwater optical LOS channels.

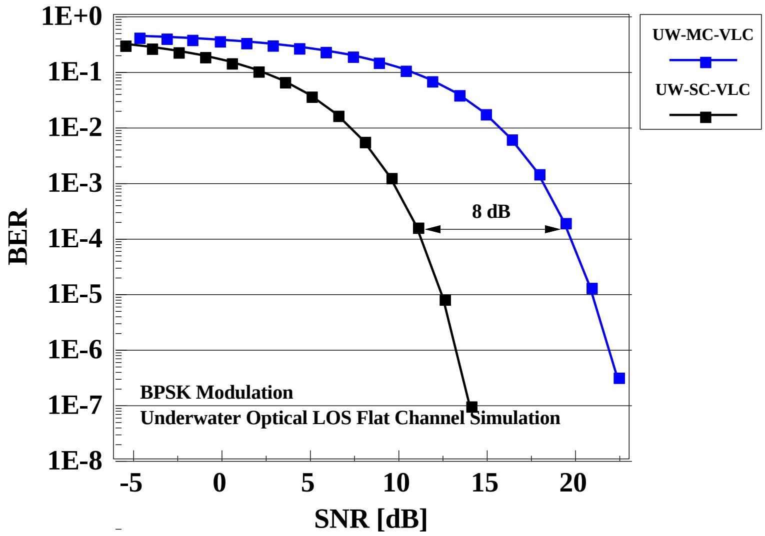

Figure 2. BER-SNR performance comparison of SC and MC-VLC systems over flat fading underwater optical LOS channel for BPSK modulation.

When investigating the BER-SNR accomplishments are provided in the flat fading underwater optical LOS channel for BPSK signal in Figure 2, it is perceived that the obtained accomplishment with the SC-VLC scheme surpasses the obtained performance with the MC-VLC system and performs roughly 8 dB SNR development for the 1E-4 BER level.

In Figure 3, the investigation of BER-SNR accomplishments of 4-QAM modulated SC and MC-VLC systems for flat fading underwater optical LOS channels is provided.

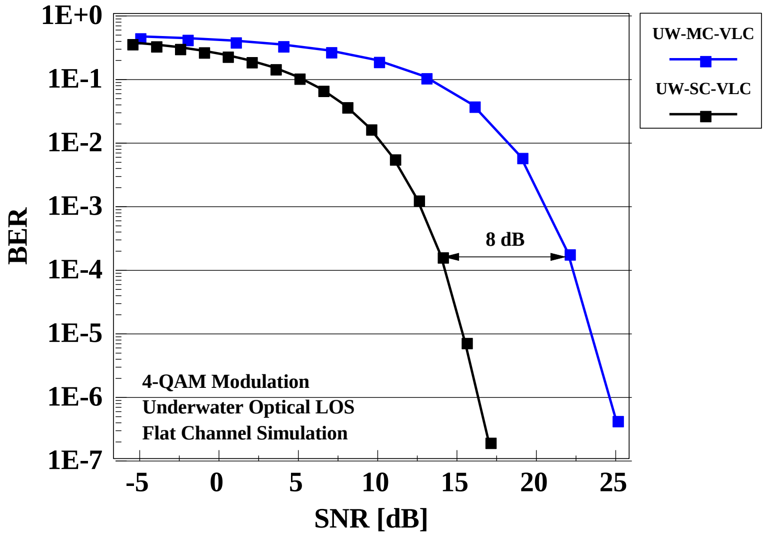

Figure 3. BER-SNR performance comparison of SC and MC-VLC systems over flat fading underwater optical LOS channel for 4-QAM signal.

When Figure 3, where BER-SNR performances are provided in flat fading underwater optical LOS channel for 4-QAM signal, is examined, alike to the previous outcomes, the obtained performance with the SC-VLC system outperforms the obtained performance with the MC-VLC system, and it is seen that it performs approximately 8 dB SNR development. It is noticed from Figure 3 that the accomplishments are continued but the SNR value increases as the modulation depth raises.

Figure 4 demonstrates the inspection of BER-SNR achievements of 16-QAM modulated SC and MC-VLC systems for flat fading underwater optical LOS channels.

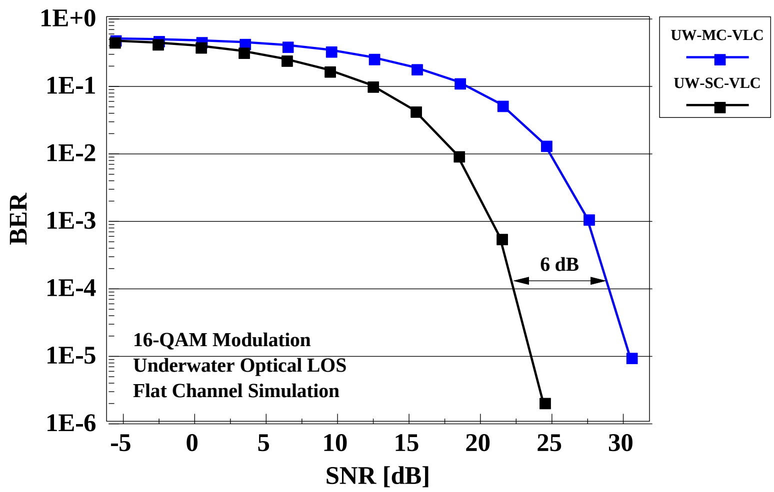

Figure 4. BER-SNR performance comparison of SC and MC-VLC systems over flat fading underwater optical LOS channel for 16-QAM signal.

As Figure 4 is evaluated, it is perceived that the acquired performance in SC-VLC systems in 16-QAM modulation exceeds the obtained performance with MC-VLC systems and performs roughly 6 dB SNR development for 1E-4 BER level. Similar to the prior outcomes, it is noticed from Figure 4 that the accomplishments are continued but the SNR value increases as the modulation depth raises.

3.2. Simulation Results of Flat Fading Underwater Optical N-LOS Channel

In the second phase of the work, the achievement of BER-SNR of SC-VLC and MC-VLC systems in flat fading underwater optical N-LOS channels are compared. Simulations are made by using the impulse response value of 2.73×10^{-7} from the underwater optical channel impulse response measurements measured in the reference (Miramirkhani et al., 2018; Miramirkhani, 2018) as the flat fading underwater optical N-LOS channel impulse response. Simulations were obtained via 1000 Monte Carlo loops, utilizing BPSK, 4-QAM and 16-QAM modulated signals with 1000 data packets of related communication systems.

In Figure 5, the investigation of BER-SNR accomplishments of BPSK modulated SC and MC-VLC systems for flat fading underwater optical N-LOS channels is given.

For BPSK signal, as the BER-SNR achievements are given in the flat fading underwater optical N-LOS channel, Figure 5 is examined, the obtained performance with the SC-VLC system outperforms the obtained performance with the MC-VLC system, and it is seen that it performs roughly 8 dB SNR development for the 1E-4 BER value. However, as Figure 5 is evaluated, it is observed that alike outcomes and developments are acquired with the flat fading underwater optical LOS channel. This can be expressed by the fact that the transmitter and receiver are very close to each other in a flat fading underwater optical N-LOS channel environment (Miramirkhani et al., 2018; Miramirkhani, 2018).

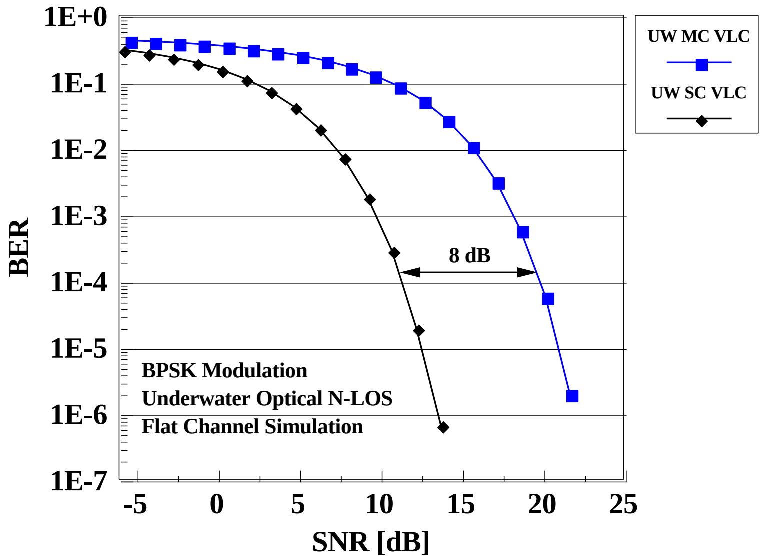

Figure 5. BER-SNR success comparison of SC and MC-VLC systems over flat fading underwater optical N-LOS channel for BPSK modulation.

Figure 6 depicts the comparison of BER-SNR successes of 4-QAM modulated SC and MC-VLC systems for flat fading underwater optical N-LOS channels.

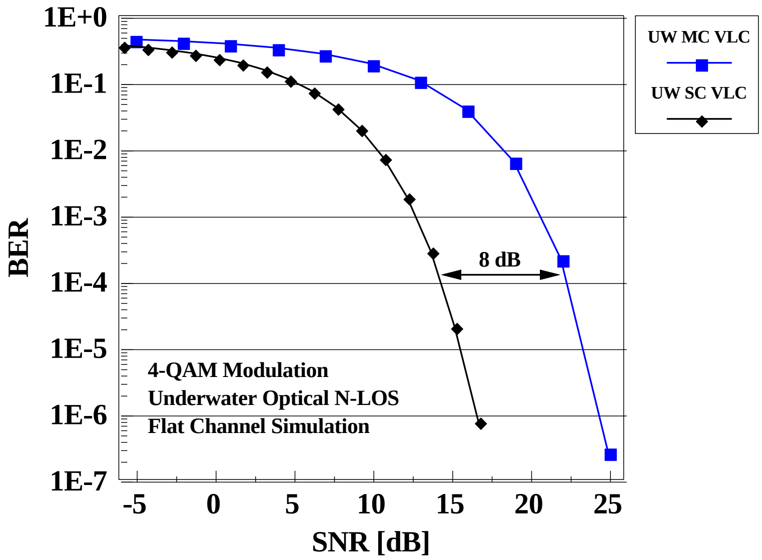

Figure 6. BER-SNR performance comparison of SC and MC-VLC systems over flat fading underwater optical N-LOS channel for 4-QAM signal.

When Figure 6, where BER-SNR performances are given in flat fading underwater optical N-LOS channel for 4-QAM signal, is evaluated, the acquired accomplishment with the SC-VLC system surpasses the performance obtained with the MC-VLC system, and it is noticed that it performs roughly 8 dB SNR gain for 1E-4 BER level. However, as Figure 6 is evaluated, it is observed that alike outcomes and alike developments are acquired with the flat fading underwater optical LOS channel as in the previous results. In addition, as the modulation depth increases, it is perceived from Figure 6 that the accomplishments are continued but the SNR value increases.

In Figure 7, the evaluation of BER-SNR accomplishments of 16-QAM modulated SC and MC-VLC systems for flat fading underwater optical N-LOS channels is provided.

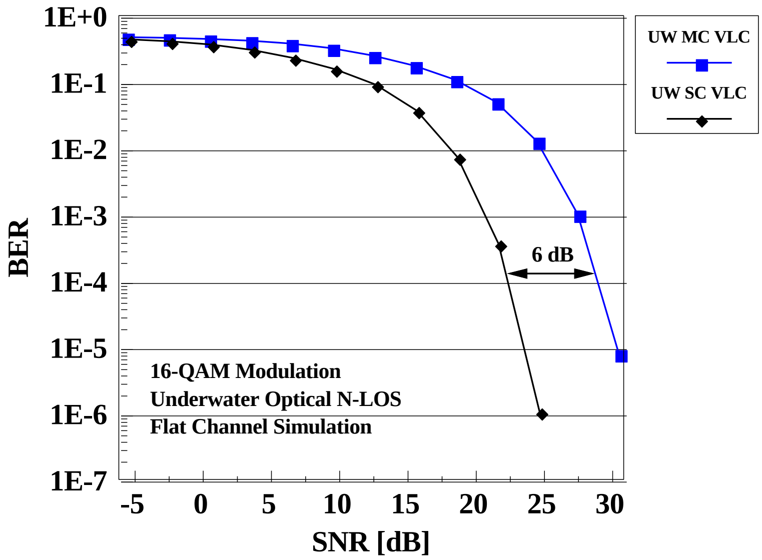

Figure 7. BER-SNR performance comparison of SC and MC-VLC systems over flat fading underwater optical N-LOS channel for 16-QAM signal.

As Figure 7 is evaluated, it is perceived that the acquired success in SC-VLC systems in 16-QAM modulation exceeds the performance obtained with MC-VLC systems and provides roughly 6 dB SNR enhancements for 1E-4 BER level. However, as Figure 7 is investigated, it is perceived that alike outcomes and alike developments are acquired with the flat fading underwater optical LOS channel as in the previous results. In addition, similar to the prior outcomes, it is noticed from Figure 7 that as the modulation depth increases, the performances are preserved but the SNR value increases.

4. Conclusion

In this study, the performance of SC and MC optical wireless telecommunication schemes is analyzed in the underwater optical channel environment. SC-VLC and MC-VLC systems using BPSK, 4-QAM and 16-QAM modulation are compared on the BER-SNR performance criteria in flat fading underwater optical LOS and N-LOS channel environments. The achievement of roughly 8 dB SNR improvement for 1E-4 BER level versus MC-VLC systems in SC-VLC systems made the study very interesting. In the light of these results, it is thought that SC-VLC communication systems in the underwater optical channel environment can be an alternative to MC-VLC communication systems for optical wireless telecommunication schemes that can be utilized for future beyond 6G implementations.

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