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Designing and Implementation of Underwater Optical Wireless Communication System

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Abstract

In modern digital communication field, optical wireless communication is playing a key role to heighten expectations of the end user. To communicate with these end users through communication channel with reliable data is always challenging and unpredictable. Nowadays, most thrust area is wireless optical communication which is used to establish connection among various end user nodes. All the constituents like fog, dust, smoke, and rain, and wind turbulence will have effect on the transmitted data or information that is transmitted through this optical channel. Moreover, this will become tricky and tiresome to detect and correct at the end of the receiver due to the altitude and the geographical location of the transceiver units of the optical communication link. This work proposes to overcome data limits of the wireless optical communication link and improve the signal to noise ratio to reduce bit error rate of 2-m wireless optical channel length. Different modulation schemes are adopted like binary phase-shifted keying (BPSK), quadrature phase-shifted keying (QPSK), and on-off keying (OOK) for wireless optical communication. However, this brings complexity in decoding and is prone to more bit error rate. To minimize the bit error, we are using the various error correction codes (repeat code, hamming, and low-density parity check codes), which will offer solution to this problem and ensure a reliable communication. The corrupted data was corrected with bit error rate of range 10^{-4}. Optical wireless communication has attracted significant interest recently in industry and academia. This special issue features a collection of inter-related papers with the intention to cover all necessary multidisciplinary challenges to realize optical wireless networks. We hope that this special issue will serve as a comprehensive reference and that it will be a resource that fosters many more new ideas for this rapidly emerging field.

Keywords: Data recovery, error correction codes, light source, modulation schemes, optical wireless communication

INTRODUCTION

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Optical communication plays a critical role in meeting user expectations in today's digital communication landscape. However, ensuring reliable data transmission through optical channels, especially in wireless setups, remains a significant challenge due to environmental factors such as fog, dust, and rain. This project focuses on enhancing wireless optical communication over a 2-m distance by addressing issues like signal interference and errors. Various techniques like binary phase-shifted keying (BPSK), quadrature phase-shifted keying (QPSK), and on-off keying (OOK) are employed for transmission, while error correction codes like repeat, hamming, and low-density parity check are applied to minimize errors and ensure reliable communication with minimal errors.

The relevance of optic wireless communication is broad and expanding. It addresses the need for high-speed, secure, and reliable data transmission in various sectors, offering a valuable alternative or complement to traditional wired and wireless communication methods. Its ability to bridge connectivity gaps and provide resilient communication in adverse conditions makes it a significant technology in today's interconnected world. Because of the big transmission capacity, good security and strong anti-jamming ability of space laser communication, it becomes a hot topic in the field of communications. The channel for the space laser communication is atmosphere, the feature of atmosphere is very random, atmospheric turbulence and flicker cause the transmission rate of space laser communications have not yet reached the level of optical fiber communication, and because of the special nature of the channel, we also make special demands for the launch power and extinction ratio of space laser communication transmit system. It is difficult for high-speed laser modulation drive circuit with discrete components. Wireless communications have become an emerging and rapidly growing field in our modern life and creates enormous impact on nearly every feature of our daily life. A tremendous technological transformation during the previous two decades has provided a potential growth in the field of digital communication and lot of latest applications and technologies are coming up every day due to these valid reasons. Digital modulation schemes contribute to the evolution of mobile communications by increasing the capacity, speed as well as the quality of the wireless network. In communication, the concept of modulation is a prime factor because without an appropriate modulation scheme, it would be impossible to achieve an expected throughput. Available bandwidth, permissible power, and inherent noise level of the system are the constraints that should be considered while developing the communication systems. Due to error-free capability in digital modulation, it is preferred over the analogue modulation techniques. The Worldwide interoperability for Microwave Access (Wi-max) uses combinations of different modulation schemes which are BPSK, QPSK, 4-quadrature amplitude modulation (4-QAM), and 16-QAM and it is a promising technology which offers high =-speed voice, video, and data services. In this paper, the literature review on the different digital modulation techniques that are generally used for the wireless communication is presented.

MOTIVATION

The intended scope of this article is to develop and test a high-speed optical wireless communication system. Traditional underwater communication encounters significant hurdles due to its limited data rate of 10 kbps over extended distances. In the contemporary landscape, wireless optical communication stands as a pivotal area of research, facilitating connections between diverse user nodes. Nevertheless, the transmission of data in this optical channel is vulnerable to environmental elements such as fog, dust, smoke, rain, and wind turbulence. This study is dedicated to resolving these challenges, seeking to enhance the efficiency of optical communication, particularly in adverse weather conditions. It offers a unique and compelling way to transmit data without the need for physical cables, making it suitable for various applications. The basic principle of optical wireless communication is based on the transmission of modulated light signals through the atmosphere. It uses lasers or light-emitting diodes (LEDs) to transmit data by encoding information in the form of light pulses.

LITERATURE SURVEY

Visible light communication (VLC) uses LEDs to transmit signals. LEDs work only in certain conditions, and negative signals get clipped. When using analog signals, flickering can occur at low to medium frequencies [1]. The system achieved a maximum data rate of 2.70 Gbps over a distance of 34.5 m using a specific modulation scheme. At shorter distances, even higher data rates were achieved, up to 4.60 Gbps at 2.3 m [2]. A measuring device encompasses various technical tools and instruments designed for measuring specific quantities. It includes instruments and auxiliary devices necessary for a particular measurement method [3]. In optical communication systems, information is transferred between two points by modulating an electromagnetic wave in the optical frequency range and transmitting it through optical fibers. Optical carrier frequencies, in the near-infrared range, offer high potential transmission bandwidth [4]. The system achieved impressive data rates, reaching up to 2 Gbps over a 12-meter-long channel and 1.5 Gbps over an exceptional 20-m-long underwater channel. The measured bit error rates (BERs) were low, meeting the standards for forward error correction (FEC)

[5]. An integrated optoelectronic receiver consisting of a photodiode and a transimpedance amplifier, both made using silicon technology (0.8 µm Bic MOS process). The research characterizes the receiver's optical and electrical properties, measuring generated photocurrent at different wavelengths and optical power levels [6]. The antenna demonstrates good radiation efficiency (ranging from 70% to 84%) and low voltage standing wave ratio (VSWR; less than 1.5) across all operating bands. The experimental validation confirms its functionality and suitability for applications like 5G mobile and wireless local area networks [7]. Underwater optical wireless communication offers higher data rates, lower power consumption, and simpler computational complexities for short-range wireless links. The paper focuses on understanding the challenges posed by underwater environments and discusses channel characterization, modulation schemes, coding techniques, and noise sources specific to underwater optical wireless communication [8]. The method employs a variable step size generalized orthogonal matching pursuit (VSgOMP) algorithm to compress the Volterra equalizer with low computational cost. The approach achieves impressive data rates, including 500 Mbps in a 7-m water tank and 500 Mbps over a 200-m underwater transmission in a 50-m swimming pool [9]. These data rates are achieved with bit error rates below the standard hard-decision forward error correction (HD-FEC) limit of 3.8×10^{-3}. The system's electrical signal bandwidth is 2.75 GHz, corresponding to an electrical spectrum efficiency of ~6-bit/s/Hz. The distance-data rate product reaches 462 Gbps*m at 35 m tap water transmission, representing a significant achievement in underwater optical communication [10].

IMPLEMENTATION

This signal is then channeled into a transmitter circuit responsible for encoding and modulating it into optical signals, with components like transistors or operational amplifiers used for amplifying the signal. The modulated signal from the transmitter circuit is then directed to a light source, typically a laser diode. The laser diode converts the electrical signal into an optical signal (light) that can travel through free space. A block diagram of underwater communication is shown in Figure 1. At the receiving end, a light detector is employed to capture the optical signal. This detector converts the incoming optical signal back into an electrical signal for further processing. The electrical signal from the light detector is then processed in the receiving circuit. This circuit is responsible for tasks such as amplification, filtering, and demodulation to recover the original data signal. To address the BER and data limits, various error correction codes are applied. After error correction and data recovery, the receiving circuit outputs the corrected data signal. To drive a green laser diode using a 2N2222 transistor and two resistors (50 ohm and 3 ohm), a simple circuit is constructed. Implementation of underwater communication is shown in Figure 2. The 2N2222 transistor is an NPN type commonly employed for low-power amplification or switching applications, used here to control the current flowing through the laser diode. The 50-ohm resistor limits the current through the laser diode to a safe operating level, while the 3-ohm resistor likely serves as part of a biasing network for the transistor. In the circuit diagram, the transistor's emitter is connected to ground, the base to a control signal, and the collector to one terminal of the 50-ohm resistor, which connects to the positive terminal of the power supply. The cathode of the green laser diode is connected to the junction of the 3-ohm resistor and the diode's anode is connected to the positive terminal of the power supply. BER readings on different parameters are shown in Table 1 and in Figure 3.

In the receiver part of our project, we used an OP-AMP LM358. We started by connecting a photodetector to the input. Then, in the main receiver circuit, two resistors with values 510 kohm and 470 kohm were connected to the inverting terminal of the op-amp. Between these resistors, there is a 430 kohm resistor grounded. The output from the op-amp is fed back to its inverting input. We provided a 12-V DC power supply to this circuit. BER versus baud rate graph is shown in Figure 3. On the non-inverting side of the op-amp, there is a 510 kohm resistor in parallel with a 100 µF capacitor, both connected to the ground. This setup allows us to receive signals effectively and process them using the LM358 op-amp.

RESULTS

The assembled prototype is presented in Figure 2 and Laser beam pass through it. Output results of bit error rate are mentioned in table.

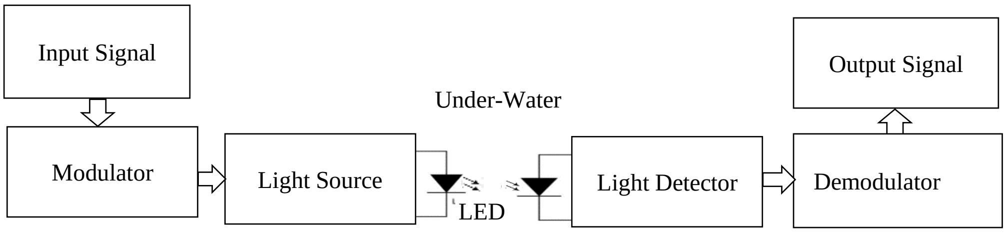

Figure 1. Block diagram of underwater communication.

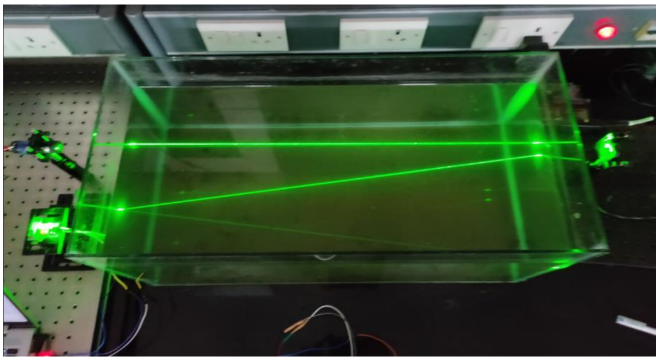

Figure 2. Implementation of underwater communication.

Bit error rate (BER) readings.

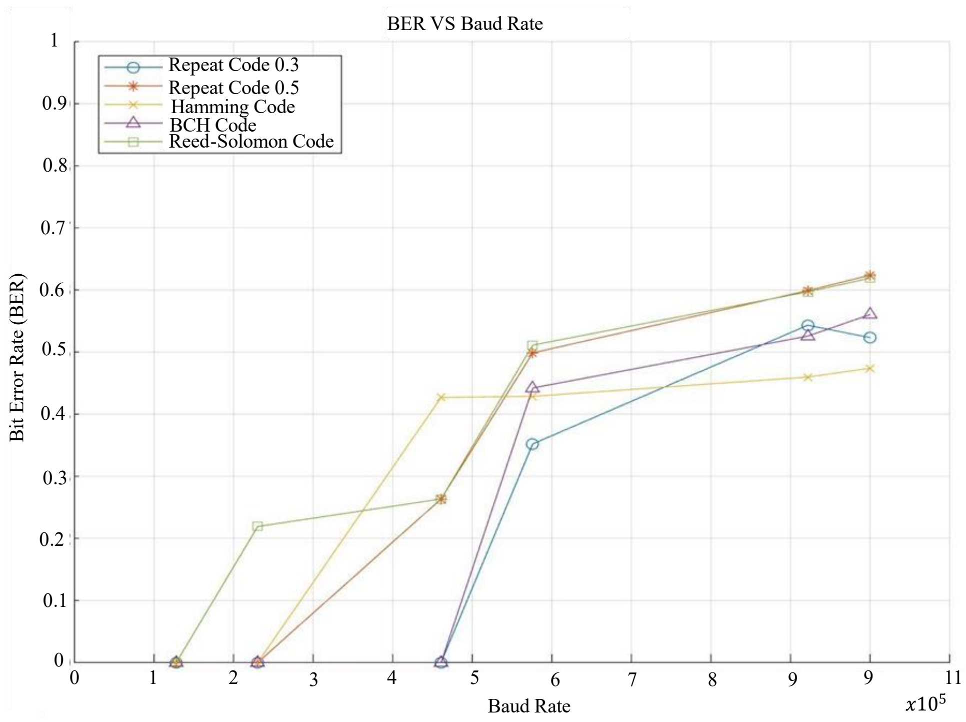

Figure 3. Bit error rate (BER) versus baud rate graph.

Table 1. Output results of bit error rate (BER) readings.

Baudrate	bch	ham	rc03	rc05	reed
128	0	0	0	0	0
230.4	0	0	0	0	0.219065
460	0	0.426832	0	0.263337	0.263337
576	0.442104	0.428676	0.35198	0.498658	0.511165
921.6	0.525629	0.459638	0.54324	0.59891	0.596992
1M	0.560428	0.473949	0.52325	0.623887	0.619015

CONCLUSIONS

The challenges of low data rates and high BERs in wireless optical communication has been overcome. Our project's achieving speeds up to 10 Mbps over a distance of 2 m and improvement compared to the previous record of 150 kbps for the same distance. This accomplishment highlights the effectiveness of our design and the potential for enhancing data transmission rates in short-range optical wireless communication scenarios. As technology evolves, the demand for faster and more reliable data transmission methods continues to grow. Our project's outcomes contribute significantly to addressing this demand, laying a foundation for further advancements in the field.

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