Performance Analysis of UWOC using SISO and SIMO Techniques

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Abstract. Underwater communication technology is challenging and so far, there is no alternate to sonar technology for wireless communication. Recently, optical wireless communication is proposed to establish reliable communication link underwater. In this paper, underwater wireless optical communication link is simulated under SISO, SIMO communication model techniques using OptiSystem tool. Link distance is enhanced by increasing the number of receivers in the communication model technique for UWOC system. The performance parameters such as bit error rate, quality factor are analyzed under different UWOC model technique for different link lengths. It is observed that as the number of receivers is increased in the communication model technique, the UWOC efficiency improves in terms of Q factor and BER.

Keywords: Underwater Communication, SISO, SIMO, Optical propagation, Wireless communication

I. Introduction

Now-a-days underwater wireless communication becoming a permissive technology has eventual employments in the range of environments from Deep Ocean to coastal sea waters. Usually the human action in underwater environment [1] is exploring the ocean and environmental monitoring [2]. In present years, there was a increasing interest in the infrastructure of scientific research development and ocean exploring system [3]. Underwater wireless communication refers to sending the data through random natured underwater environment using wireless carriers [4] that is RF, sound and optical waves [5].

Radio frequency method uses electromagnetic waves and it is operating at a extremely low frequencies, for shorter distances this method provides high data rate and it performs smooth transition through the air and water environments [6]. The main degrading effects of RF method is signal used in this method is highly attenuated by sea water[7] and so it is limited to short range communication and the transmitters and receivers are very bulky and costly and finally attenuation is more [8]. Next is acoustic communication [9] which is very utilizable for extended link range communication and distance up to km. This system is most demanding technique for transmitting information in underwater wireless communication and has been used during the time of world wars [10]. There are certain limitations for acoustic communication which degrades the performance such as multiple path variations and high delay [11]. In comparison with radio frequency technique and acoustic technique, optical supports sizably voluminous bandwidth and it supports high data rate up to Gbps for shorter distance, medium range over hundreds of meters and low latency [12]. The equipment used
for this technique is low cost and small volume of transmitters and receivers. The main challenges are in underwater wireless optical communication is loss of optical power with link length and it is primarily affected due to scattering, turbulence and absorption [13]. The optical turbulence is caused by the salinity, existence of air bubbles and temperature differences in water [14].

In order to overcome these limitations in single input and single output system we are going for single input multiple output technique. The limitations of SISO system is unprotected to problems caused by the multipath effects. In underwater environment if the light signals come across any obstruction in water then the wave fronts are scattered and thus it will take numerous paths to reach the destination. The scattered portions of the signal cause fading. Due to this there is reduction in data rate and it may increase the BER. In order to mitigate these problems mainly caused by multipath propagation MIMO technique can be implementing in future. Majorly SISO is applicable in radio, satellite, GSM and CDMA systems. The schematic diagram of SISO system is depicted in Figure 1.

Figure 1: Block diagram of SISO system.

Received signal for SISO system can be given by

\[ Y = aH + n \]  

(1)

where ‘a’ denotes the input signal, ‘H’ is channel coefficient, and ‘n’ indicates white Gaussian noise.

As we know that MIMO technology is multiple input and multiple output-based technology means more than one antennae are used at the transmitter and receiver sections. The advantages of MIMO are it helps to achieve the higher data rates or throughput with the help of multiple transmitters and also MIMO offers high quality of service with increasing data rates [15]. The main reason for using the MIMO system design is to minimize the fading effects in between the transmitter and receiver end. But in this paper we implemented single input multiple output system and further for the improvement of system performance MIMO technique can be implement in future. The drawbacks of SIMO, MISO and MIMO are resource requirements and hardware complexity is higher, Hardware resources increases power requirements. Battery drains faster due to processing complex things. This may lead to affect the battery lifetime of devices. It is costlier compared with single antenna-based system due to hardware and software requirements.

II. Spatial Diversity MIMO Technique

A diversity scheme is a method that is utilized to spread information for several signals transmitted over unconventional fading paths. Spatial diversity is also identified as Antenna diversity or space diversity, this diversity scheme that uses two or more antennae are used in order to enhance the quality of wireless link. This technique is especially used in city environments, it can also be implemented in submerged environment because there is no clear LOS between transmitter and receiver, due to which signal gets reflect into multiple paths before receive at the photodetector. So these reflections can introduce attenuations, delays, phase shifts and distortions that
can violently interface with one another at the aperture of receiving antenna. Spatial diversity is mainly helpful at mitigating the multipath situations because of multiple antennae which offer to receiver, many considerations of same signal [16]. Each antenna will encounter distinct interface environments. Therefore, if one antenna is facing deep fade, another one has adequate signal. Accordingly such system can provide strong link. There are number of different MIMO schemes that can be used, termed as SIMO, MISO and MIMO. These MIMO configurations having its own advantages and disadvantages, these can provide optimal solution for any given application [17]. There are many different systems of antenna technology are available refer to SISO and MIMO. The following paper discussed about multiple antenna schemes which is presented below.

- Single input multiple output (SIMO)
- Multiple input and single output (MISO)
- Multiple input and multiple output (MIMO)

In this paper, we designed the SIMO; it is one of the MIMO techniques where the transmitter having one antenna and receiver has more antennas. It can also define as Receiver diversity. It is frequently used to allow a receiver system that received signal from a number of unconventional sources to counter the effects of fading and interference. Switched diversity MIMO scheme and Maximum ratio combining scheme are the two different types present in SIMO [18]. The Simple block diagram for SIMO are given in Figure 2

\[ Y = aH + n \]  

Where \( H = H_{11} H_{12} \)

where ‘\( H_{11} \)’ is channel coefficient for first transmitter antenna and first receiver antenna, whereas ‘\( H_{12} \)’ is channel coefficient for first transmitter antenna and second receiver antenna, ‘\( a \)’ denotes input signal and ‘\( n \)’ indicate the white gaussian noise and ‘\( Y \)’ is the received signal.

III. UWOC System

The system diagram in Figure 3 shows the wireless underwater optical communication system design. The important and crucial challenge in underwater wireless optical communication is loss in received optical power with link length. Absorption, turbulence and scattering because of suspended particles are main factors for attenuation. The main reason for absorption of signal is because of presence of water particles, inorganic and organic substances present in different nature of water. Generally in ocean it involves diffused salts like sodium (Na), chloride (Cl) and magnesium that absorbs light at particular wavelengths. Usually pure water is slightly affected by attenuation in the 450nm-550nm range. The low attenuation of blue and green light in water channel supports evolution of underwater wireless optical communication.
Therefore, the transmitter used in this test is 450 nm blue laser diode and receiver as si-photodetector (PD). The input power is maintained at 3mW and here tap water is used as channel and power is noted with the help of power meter for various channel link lengths. This optical signal is communicated through a water channel and it is received on Si-PD and output power is noticed on power meter. The Figure 4 shows the experimental setup of the UWOC.

![Figure 3: Block diagram of UWOC system](image)

![Figure 4: UWOC system experimental setup with dimension of 180 x 42 x 60 cm](image)

Experiments are performed under different channel conditions like water channel in the existence of air bubbles, salinity and turbidity. Based on the experimental results channel modelling is done by fixing the acquired experimental data with relatable expression. The nature of received optical signal in any medium obeys Beer – Lambert’s Law [2]. Therefore, we tend to come back up with a generalized mathematical equation which can do the simplest work and procure the constants.

\[
P(x) = a \times \exp(-b \times x)
\]

(3)

The mathematical expression is given in above equation (3) where \(x\) is channel length, \(p(x)\) indicates the received optical power, \(a\) and \(b\) are arbitrary constants that depends on attenuation (A) and also the refractive index (RI) of channel. The constants \(a\) and \(b\) are evaluated for different channel condition and thereby a mathematical channel model is arrived at for a given channel.

**IV. Simulated Results and Discussion**

Practically setting up a MIMO system underwater is complex and costly. Therefore, in this paper to mitigate the turbulence effect SIMO scheme is proposed and simulation is carried out to study the performance enhancement. In order to model the underwater
wireless optical channel (UWOC) in OptiSystem tool, mathematical equations are formulated based on the obtained experimental data and with the help of the formulated mathematical equations, an UWOC channel component is developed in OptiSystem tool. The underwater wireless optical channel (UWOC) is modelled in MATLAB based on experimental data and then exported to OptiSystem. The layout diagram of single input and single output UWOC system is shown in Figure 3. The simulation parameters taken into consideration in the analysis are tabulated in Table 1.

| Table 1: Simulation Parameters |
|------------------------------|
| Simulation Parameter | Values and Unit |
| Transmitted power | 200 mW |
| Operating Wavelength | 450 nm |
| Bit rate | 1 Gbps |
| NRZ pulse generator | 1 a.u |
| AM Modulation index | 1 |
| PIN Photo detector responsivity | 1 A/W |
| Dark current | 10 nA |
| Low pass Gaussian filter- cutoff frequency | 0.75 * Bit rate |
| Transmission distance | 0 ≤ Lc ≤ 329 cm |
| Absorption Coefficient (a(λ)) for Pure water | a(λ) = 0.02381 cm⁻¹ |
| Air bubbles | a(λ) = 0.02864 cm⁻¹ |
| Salinity | a(λ) = 0.07818 cm⁻¹ |
| Turbidity | a(λ) = 0.0922 cm⁻¹ |

**Point - to - Point UWOC system**

The schematic layout of point – to – point UWOC system in Opti System is shown in Figure 5. Optical signal is generated by a continuous wave laser with wavelength of 450nm and input power 200mW. Pseudo random bit sequence generator generates the random bit sequence with bit rate of 1Gbps and it is given to the NRZ pulse generator for generating the electrical pulses. The output of continuous wave laser and Non Return to Zero pulse generator are given as inputs to the AM modulator. AM modulator modulates the data present in the electrical signal on to the optical carrier. This modulated signal is given to the underwater wireless optical channel which is modelled in MATLAB based on the equations formulated from the experimental results. The output of UWOC channel is given to the photodetector and is observed on an oscilloscope. It can be seen laser beam has an output power level of 200 mW in Figure 6 (a). The Figure 6 (b), gives the NRZ formatted random bit sequence at 1 Gbps. Optical spectrum and Optical time domain waveforms at AM modulator are appear in figures 6(c) and 6(d). From the optical spectrum Figure 6(c), we confirmed that the wavelength of operation is 450 nm. From Figure 6(d) it can be shown that the optically modulated signal follows the electrical signal pattern in Figure 6(d). The Figure 6(e) illustrates the received optical signal, because of absorption and scattering effects the power is attenuates drastically in the underwater channel. The converted electrical signal at photodetector is shown in Figure 6 (f), thermal noise and dark current present in the photodetector are responsible for the distortions present in the waveform obtained at the output of si-photodetector.
Figure 5: Layout of Point-to-Point UWOC system in Optisystem

Figure 6 (a): Laser input signal

Figure 6 (b): Electrical input signal

Figure 6 (c): Optical spectrum at output of Amplitude Modulator

Figure 6 (d): Optical time domain waveform at Amplitude Modulator
Figure 6 (e) Received Optical Signal

Figure 6 (f) Converted electrical signal at photodetector

Figure 7: Eye diagram at the output of detector for Point – to – Point UWOC system

Figure 7 shows the eye diagram for Point – to – Point UWOC system. The simulation is carried out for different underwater channel lengths, and it was found that the
performance degraded with increasing length. The performance parameters are tabulated in Table 2 for a link length of 231 cm, beyond which the performance degrades.

Table 2: Performance Parameters of Point – To – Point UWOC System

| Parameters     | Values         |
|----------------|----------------|
| Q-factor       | 5.619          |
| BER            | 9.550 x 10^{-9}|

Receiver Diversity Scheme

In order to improve the efficiency of UWOC, receiver diversity scheme SIMO is studied.

Single Input Multiple Output (1 x 2) UWOC system

The schematic layout of single input and multiple output system (1 x 2) in Optisystem is shown in Figure 8. By increasing the receiver diversity, we assume that the modulated optical signal from the source will propagate through water channel with different characteristics. On reception the signal with better BER is chosen for analysis. For 1 x 2 we used Array waveguide grating (AWG) in order to separate the optical signals into two different underwater wireless optical channels which is modelled in MATLAB based on the equations formulated from the experimental results. The output of two UWOC channels is given to the photodetector and is observed on oscilloscope.

![Figure 8: Layout of single input and multiple output (SIMO) 1 x 2 system in Optisystem](image-url)
Figure 9: Eye diagram at the output of detector for SIMO (1 x 2) UWOC system

Figure 9 shows eye diagram taken from the output which shows the better efficiency in terms of Bit Error Rate and Q factor. The performance parameters are tabulated in Table 3 for a link length of 329 cm.

Table 3: Performance Parameters of SIMO (1 X 2) UWOC System

| Parameters | Values |
|------------|--------|
| Q-factor   | 5.612  |
| BER        | 9.959 x 10^-9 |

From the simulated results it can be observed that the performance is enhanced in terms of link length and BER.

Table 4: Comparison of Various Performance Parameters for Different UWOC Systems

| System | Input power | Bit rate | Link length | Q-factor | BER         |
|--------|-------------|----------|-------------|----------|-------------|
| 1 x 1  | 200 mW      | 1 Gbps   | 231 cm      | 5.619    | 9.55 x 10^-9 |
| 1 x 2  | 200 mW      | 1 Gbps   | 329 cm      | 5.612    | 9.95 x 10^-9 |

Comparison of SISO and SIMO for various parameters of two different channels is listed in Table 4. From table 4, it is found that the link length is increased in UWOC SIMO system and performance is enhanced in SIMO technique in terms of BER.
**V Conclusion**

In order to strengthen the efficiency of underwater wireless optical communication link, SIMO technique is implemented and its performance is analyzed. The performance parameters of SISO, SIMO techniques on the subject of Q factor and BER are observed for multiple receivers in OptiSystem software. Eye diagrams for each of the implemented schemes are observed which depict the quality of the received signal. It is observed that, as the number of received antennae is increased in the SIMO technique, the performance in terms of BER improves. From this observation we can say that in future as the number of transmitted and received antennae is increased in the MIMO scheme, link length of the UWOC channel increases.

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