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AN OVERVIEW ON EVALUATION OF HYBRID UNDERWATER WIRELESS OPTICAL-ACOUSTIC NETWORK

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ABSTRACT

The arrangement of underwater networks permit researchers to collect explorative and monitoring data on underwaterEnvironment. The acoustic medium has beenbroadlyutilizes in current research and commercial uses but the optical medium become experimental only. We present a hybrid solution which combines both acoustic and opticalcommunication that can be used to overcome the limitation of bandwidthof the acoustic channelby allowing optical communication with thehelp of acoustic-assisted alignment link between optical transmitters and receivers.This paper presentsa new underwater wireless link design using hybrid optical/acoustic.The design comprises of high directivity, high-bandwidthoptical uplinks from divers to a base station and a low bandwidth, wide-angle downlink. The limiting accomplishmentfactors for the acoustic and optical visible features were found through respective channel modeling and Signal to Noise Ratio's. The bitrate of the hybrid link is greater than a traditional acoustic link by a factor of 150. Main issues such as susceptibility to variation in Natural Ocean, opticallink misalignment and acoustic latency are discussed

Keywords: Acoustic communication, Channel modeling, Optical wireless communication, underwater communication, Signal-to-noise ratio

I. INTRODUCTION

Our planet is covered by water more than 70%. Demands for underwater communication systems are increasing due to the growth of human actionsin underwater environments such as environmental monitoring, underwater exploration, and offshore oil field exploration. However, traditional underwater acoustic communications does not provide high data rates to allow monitoringtechnology. Optical wireless communications, centered on blue-green wavelengths, have been identified as a risingalternative, recently show definitively bandwidths beyond 1 Gb/s [1] and links up to 200 meters in length [2]. Research taken in this field is compelled by making advancementin terrestrial visible light communication technology. A unique challenge in the underwater environment is how to design a fully duplex communication link. Underwater optical duplex communications are prevented by the large volume of back-scattered light caused by the ocean. The light of the return signalcan be indistinguishable fromback-scattered light. There are methods to reduce the amount of back-scattered light are detected, such as through polarization or using asubstitute wavelength for the return signal [3], reduce the overall optical system achievements.The purpose of this research is to develop a new duplex underwater link design which can be used for ocean and environmental monitoring which utilizes the strong features of both acoustic and optical communications. The main application of attraction to this paper is communication between a driver or ships, with unmanned underwater vehicles (UUV)and Automatic underwater vehicle (AUV).

II. ACOUSTIC COMMUNICATION

It covers the basic belonging of acoustic communications, an evaluation of using acoustic network and the attenuation of acoustic signals.

2.1 Summary of an AcousticCommunications

The radio wave communications (e.g., Wi-Fi, Zigbee) are inappropriate for underwater communications because water severely absorbs electromagnetic waves and to drop the radio wave signal strength. For research and commercial uses we use acoustic communication in underwater communications. Underwater acoustic networking is famousbecause: acoustic signals can be propagated over long distances, providing a large range oftransmission;it broadcasted sound waves so that they have a wide field-of-view and frequently spread the signal Omni-directionally. When an obstacle is situated in the line-of-sight between sender and receiver, sound waves follow a path through non-absorbing materials, or go over the obstacle via a wide field-of-view. Due to these advantages acoustic communication does not rigidly require line-of-sight.

There are several drawbacks in acoustic communication: the speed of sound waves is comparably easy than electro-magnetic waves which concludein propagation delay between sender and receiver (around 1513.74m/s) is slow down. Due to this data rate become slow and acoustic communications result in highly limited bandwidth. Acoustic signal is broadcasted by increasing the frequency, but when we increase the frequency larger attenuation and higher energy consumption takes place, which will be considered in section 2.3.

2.2 Acoustic Communications in Networking

For networking purpose we use acoustic signal in which sender nodes capable of broadcasting the receiver nodessignal in that case network characteristics are matched with existing wireless networks like Wi-Fi. Acoustic networking has similar problems as terrestrial wireless networks, such as the unseen terminal effect, interference, and collisions of signal. Interference issues are worse because speed of sound in water is much slower than the speed of electromagnetic waves in air.

Qadri and Shah [4] have judged the performance of applying existing routing protocols Dynamic Source Routing, Destination-Sequenced Distance-Vector Routing, Optimized Link State Routing and Ad hoc On-Demand Distance Vector Routing, (DSR, DSDV, OLSR and AODV) have been used in underwater acoustic sensor networks. It concludes that DSR is not appropriate because it has low packet delivery ratio and throughput. OLSR is not appropriate due to its high energy-consumption. AODV and DSDV have better performance in which AODV is appropriate for denser network of less traffic while DSDV is appropriate for high traffic of daily network.

2.3 Acoustic Signal Attenuation

The important aspect in evaluating the performance of wireless communications is the attenuation of signals at different conditions.

Approval to the work by Stefanov*et al.*in [5], the attenuation of acoustic signals can be designed by the following equation:

$$A\ (d,\ f) = A_o\, d^k\, \alpha\ (f)^{\ d} \qquad (1)$$

Where A(d, f) represents the amount of attenuation over distance d and frequency f, and the normalizing constant A_0 and spreading factor k = 1.5 are fixed values.

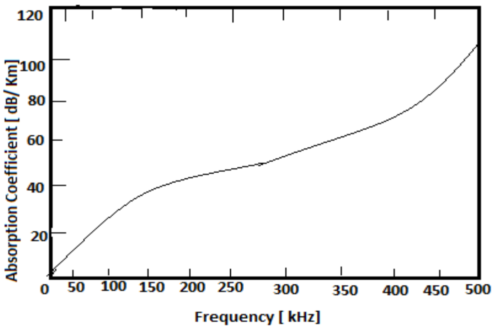

Fig.1 Absorption coefficient versus frequency

According to this equation, as distance d increases then the amount of attenuation A also increases. This equation shows that the distance between receiver node and sender node is long then it is difficult to transmit the signal. . We observe that the absorption coefficient α (f) described by the Thorp's formula [6] show relationship between absorption coefficient and frequency.

III. OPTICAL COMMUNICATION

It covers an overview of optical communications, an evaluation of using optical networks, and the attenuation of optical signals.

3.1 Overview of optical communications

Optical communications are presently experimental in underwater networks and include several researches [7], [8], [9] and [10]. Optical communications have several advantages: higher bandwidth at lower energy consumption rate, lower propagation delays. Regardless of higher throughput at lower power, optical communications suffer from larger attenuation, an issue that will be considered in section 3.2. Optical communication has narrower field of view and requires line-of-sight between sender and receiver discussedin section 3.3.

3.2 Optical signal attenuation

Optical signals have limited range due to higher attenuation. Anguita*et al.*[11] modeled the power of optical signals at receiver side in the following formula:

$$P = \frac{2 P_0 A_r \cos\beta}{\pi L^2 (1-\cos\theta) + 2AA_t} e^{-\alpha t} \qquad (2)$$

Where, area of receiver (A_r), distance to receiver (L), transmitter light beam diverge angle (θ), attenuation coefficient (c), inclination angle to receiver (β), distance to sender (d) and area of transmitter (A_t),. The relationships betweenβ and θ are illuminated in Figure 2.

The inclination angle β denotes distance from receiver node B is from the center of sender node A's signal. The transmitter light beam diverge angle θ denotes one half of the field of- view of sender A's signal. According to Equation 2,as β increases up to 90 degrees, the power decreases. The signal attenuation increases when receiver node B away from light beam. Therefore, we can observe that a larger field-of-view also results in higher attenuation. In conclusion, the optical communications requires both a narrower field-of view and direct line-of-sightfor optimized receiving power.

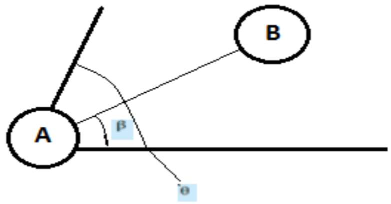

Fig.2 Inclination angle β and transmitter light-beam diverge angle θ

3.3 Using Optical communication in networking

Speed of propagation is the primary difference between the acoustic and optical communication. When in water, the propagation speed of sound is roughly 1500 m/s. The propagation speed of light in water is 2.55 * 10_8 m/s, slightly slower than the 3.00 * 10_8 m/s of air. Inother words, the propagation speed of light is five orders of magnitude slower than the propagation speed of sound. When comparing the two methods of transmissions the tradeoff between transmission range and bitrate must also be considered.

Figure 3 is a chart showing the different acoustic and optical modems currently available. The optical modems are presented inthe top left corner; their bitrates are orders of magnitude higher than the acoustic modems and are measured in terms of megabits. The acoustic modems are spread out along the bottom half of the graph, with a wide range of bitrates and distances.

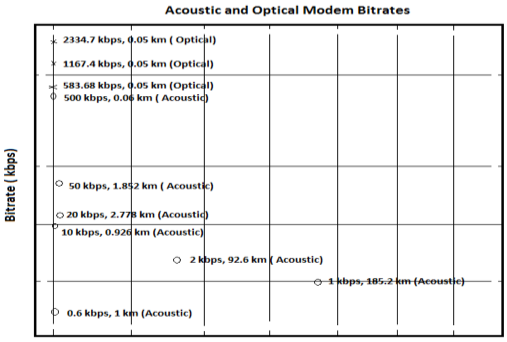

Fig.3Acoustic and optical modem bitrate

In Table 1 below, we see the conclusions drawn previously summarized by Farr, *et al*. [12]. The power efficiency of optical communications is significantly higher than acoustic communications. Another differing aspect between optical and acoustic communications is the field of view required by the modems. Acoustic communications can be omnidirectionaland do not require direct line of sight between sender and receiver but line of sight require for optical communication.

Telemetry Methods	**Range**	**Data Rate**	**Efficiency**
Acoustic	Several Km	1kbps	100 bits/ joule
Optical	100 meters	1Mbps	30,000 bits/ joule

Table1. Acoustic Vs. Optical

IV. HYBRID SOLUTION

4.1 Objectives of hybrid solution

A tradeoffin terms of power, range, and bitratein the acousticand optical communications. These tradeoffs must be balanced between acoustic and optical communications. Section 4 showed that optical communications had a higher bitrate and lower energy consumption, but shorter range as compared to acoustic. Acoustic communicationshad a slower bitrate and higher power consumption, but alsoa much longer range. In order to use the benefits of both solutions, a hybrid solution is mandatory.

In Figure 5, represent the possible solution of hybrid network. In the hybrid solution, an Autonomous Underwater Vehicle (AUV) is equipped with both acoustic and optical modems. The AUV consists of three acoustic receivers, an acoustic transmitter, an optical transmitter and an optical receiver. Within optical communication rangethe optical transmitter and receiver can be used to communicate with other nodes..

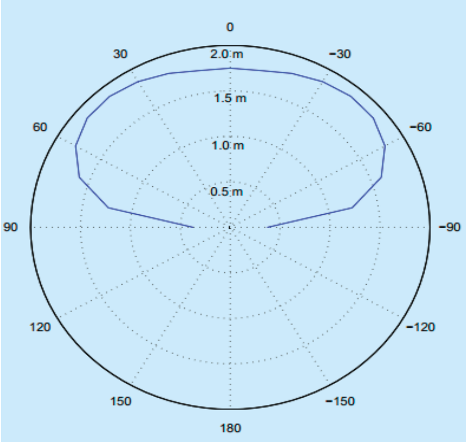

Fig.4Field of view of optical transmissions

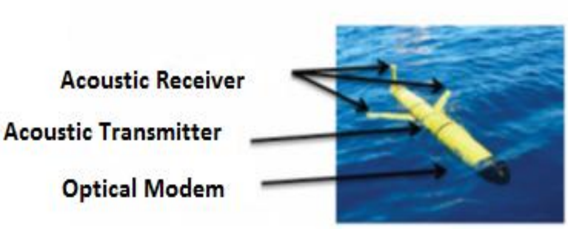

Fig.5Example of Hybrid Solution

4.2 Hybrid Transmission

To properly utilize both types of communicationpossible, the following algorithm is proposed when node A' wants to transmit to node B':

- Node A' sends an acoustic signal to Node B'
- Node B' uses the information to triangulate the positionofNode A' and turns to alignto Node A'
- Node B' sends an acoustic response to Node A'
- Node A'uses the acoustic response from Node B' to triangulate the position of Node B'and align to Node B'
- If Node A' is currently out of optical communication range, it proceeds to move into range to transmit while using the acoustic modem to transmit data.
- Once Node A' is in optical communication range, it either switches to using the optical modem exclusively for transmissions, or uses a combination of both the acoustic and
- Optical modems to transmit data.

In the algorithm above, a node uses an acoustic modem when the receiver is out of range of optical communication. If the distance is close enough for optical communication range, then it will use optical communications after alignment. In the cases where the distance between the two nodes is long then using acoustic communications as it does not require alignment.

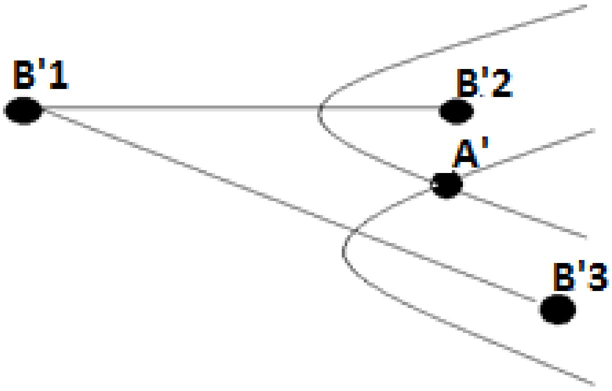

Fig.6Time difference of arrival

V. CHANNEL MODELS

In the underwater environment electromagnetic and acoustic waves behave distinctive. Propagation for optical signals depends on the optical properties which are straightly related to the composition. On the other hand, when composition changes which change primarily with bulk refractive index only have a secondary effect on acoustics.

5.1 Acoustic Propagation

For link z meters long at frequency ftotal path loss in an acoustic channel, is given by [5]

$$A\ (d,\ f) = A_o\, d^k \alpha\ (f)^{\,d}$$

Where$A_o$is a unit-normalizing constant which includes fixed losses, α (f)is the absorption coefficient, d is the distance and *k* is the spreading factor, typically quoted as 1.5. The absorption coefficient is frequency dependent and can be supposed using Thorp’s empirical equation (valid when $f > 5$ kHz) [5]

$$10 \log a(f) = \frac{0.11f^2}{1+f^2} + \frac{44f^2}{4100+f^2} + \frac{2.75f^2}{10^4} + 0.003 \tag{3}$$

Wheref is frequency measured in kHz and α (f) is the attenuation coefficient in dB/km. Equation (3) has been plotted in figure for the range 5 kHz <f <300 kHz. Attenuation increases significantly with frequency where the bandwidth becomes double from 30 to 60 kHz that causes the acoustic absorption becomeapproximately double.

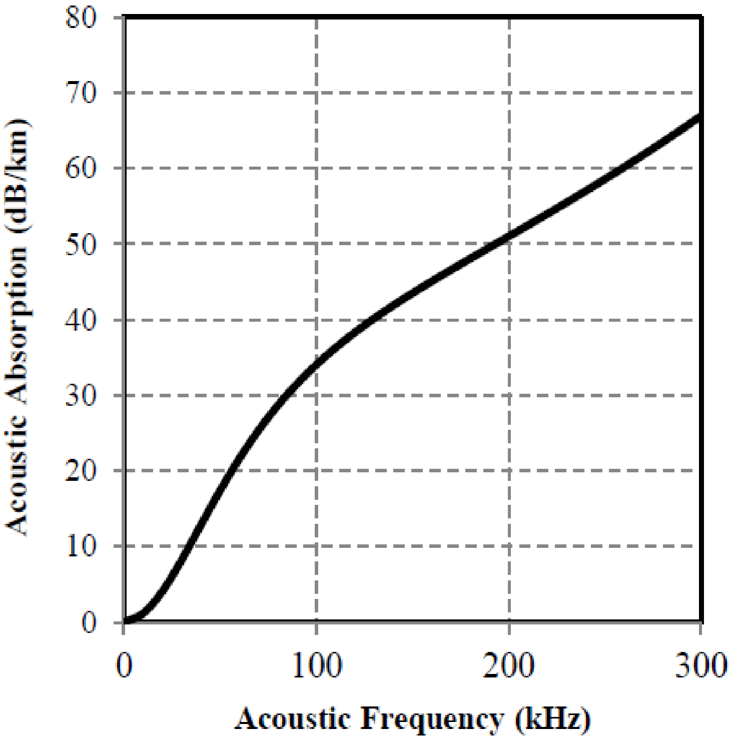

Fig.7. Channel properties of different underwater communication schemes, where a) acoustic absorption coefficient with varying frequency

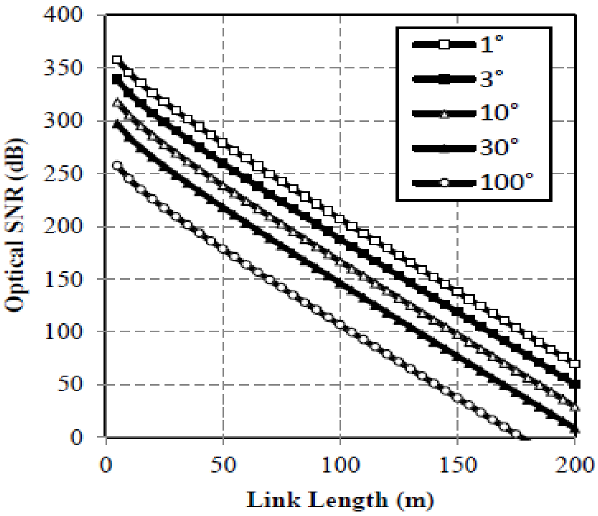

Fig 7. Channel properties of different underwater communication schemes where b) optical SNR with increasing link length and transmitter FOV.

The acoustic transmission loss is used to calculate the signal-to-noise ratio (SNR), where the power spectral density of the transmitted signal and N is the noise figure [13]:

$$SNR(z,f) = \frac{S_z(f)}{A(z,f)N(f)} \tag{4}$$

This relation means it is possible, with acoustic systems, to communicate beyond 1000 kilometers [14], lower transmission bandwidth and initial power high; medium length links of 100-1000 meters support up to20-50 kHz [15]. The acoustic equivalent of the optical field-of-view (FOV) is typicallywide-angle about 60 to 100° andangle can be increased by adding power at the transmitter.

5.2 Optical Propagation

Optical attenuation is caused by scatter and absorption of transmitted photons. The losses are characterized by the attenuation coefficient *c*, which is reliant on the source wavelength. Partial transmission loss O can be described by following equation:

$$O(z,\lambda) = e^{-c(\lambda)z} \tag{5}$$

Where λ is the transmission wavelength. When we depend upon wavelength, attenuation is influenced by the optical signal, which for the ocean is a direct consequence of the composition. Attenuation coefficient varying by up to an order of magnitude from 0.1 m^{-1} in clear open oceans to 2.19 m^{-1}near littoral shorelines [16]. The optical Signal to Noise Ratio is found from the transmission loss through [15]:

$$SNR(z,\lambda) = \left[\frac{P_T O(z,\lambda) D^2 \cos\phi}{(\tan^2\theta) 4z^2 N_o}\right]^2 \tag{6}$$

Where P_T is the transmitter power, *D* is the receiver aperture diameter, Øis the offset angle between the center ofthe transmitter and receiver, N_o is the noise equivalent power andθ is the transmitter FOV. The SNR in (4) has been plotted in figure 7 b) for several transmitter FOVs, with increasing link length, where λ = 445 nm, *c* = $0.15m^{-1}$, P_T= 100 mW, D = 0.01 m^2, Ø = 0° and No= 9.9 x10-22 Watt. This figure shows how rapidly the signal qualitydecreases with FOV and distance increases; a 100 meter a 1° link has the same SNR attainment as a 40 meterlink with a 100° FOV.

Optical links are more energy active than acoustic, typically 30,000 bits per Joule compared with 100 bitsper Joule [17]. The design of duplex systems for these optical links is challenging due to the amount of back-scattered light in either transmission when the same wavelengths are used for transmission. If alternative wavelength is used for the arrival signal, the SNR attainment to deteriorate as the attenuation coefficient increases.

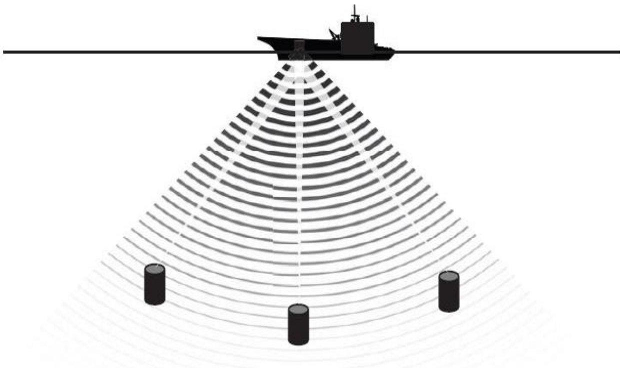

Fig 8. Hybrid communication link environment

VI. CONCLUSION

In this paper we explored the properties of both underwater acoustic and optical communications. We proposed the concept of hybrid system where a node is equipped with both acoustic and optical modems.As a conclusion to this research, there are number of performance issues for the hybrid optical acoustic link design wasevaluated. These issues include susceptibility to changes in seawater properties, the effect of optical link misalignment and latency in the acoustic link.A hybrid communication system can transmit high data rate information by using optical transceiver. When the water turbidity is huge or the distance between the terminals is abundant, the system can be exchange to low data rate by using the acoustic transceiver. This will increase the average data rate and availability of the system.

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