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Study of Wireless Sensor Network Based on Optical Communication: Research Challenges and Current Results

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ABSTRACT

With the rapid developments of commercial demands, a majority of advanced researches have been investigated for the applications of underwater wireless sensor (WSN) networks. Recently optical communication has been considered for underwater wireless sensor network. An experimental set-up for testing optical communication underwater has been provided and designed in present papers to maximize the energy coupled from these displacements to the transduction mechanism that converts the mechanical energy into electrical. The true case has been considered by measuring diffuse attenuation coefficients in different seas. One stand out potential optical communication method, Visible Light Communication (VLC) has been talked and several communication methods are compared from many points of view, for example attenuation in salt water. The evaluation of modulation techniques for underwater wireless optical communications has been displayed, and further how the data collection and storage with an underwater WSN is introduced. In this paper current researches for an (UWSN) based on optical communication are studied, in particular the potential VLC method and comparisons of VLC with other optical communication approaches. Underwater challenges would be analyzed by comparing a sort of communication methods, applied in underwater. Future work will be developed at last.

1. Introduction

High efficiency Underwater Wireless Sensor Networks (UWSN) is hard to be designed for underwater wireless communication applications. What is known to us is that the medium water has a significant attenuation for Radio Frequency (RF) radio waves. In order to degrade this problem, sonar communication, infrared wireless communication, optical wireless communications, based on laser and Visible Light Spectrum have been investigated in [1,3,9]. Due to the limited resource of spectrum and its big advantages of VLC system, an application of VLC on UWSN stands out, which can be used to detect the environmental condition in deep sea, lift condition of marine organisms etc. This paper analyses the challenges by applying the optical communication techniques and describes the details of current researches and derived results on VLC in UWSN. Following that, the future work for enhancing VLC based on LEDs will be explored.

This paper is organized as follows: Section II depicts the (UWSN) challenges by comparing existing telecommunication techniques and a short introduction of structure of UWSN. Section III describes current result achieved and potential research challenges on UWSN system. Section IV concludes this paper and declares future work.

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2. Underwater Challenges

Wireless sensor network (WSN) (Figure 1a) is the spatially distributed autonomous sensor to monitor physical or environmental conditions, (e.g. temperature) and to cooperatively pass their data through the network to a main location. The development of wireless sensor networks was motivated by military applications such as battlefield surveillance. To produce low-cost and tiny sensor nodes is a major challenge in WSN and a majority of the nodes are still in the research and development stage, particularly their software and also inherent to sensor network adoption is the use of very low power methods for radio communication and data acquisition. However the most interesting part is about Underwater WSNs (UWSNs) (Figure 1b).

a)

b)

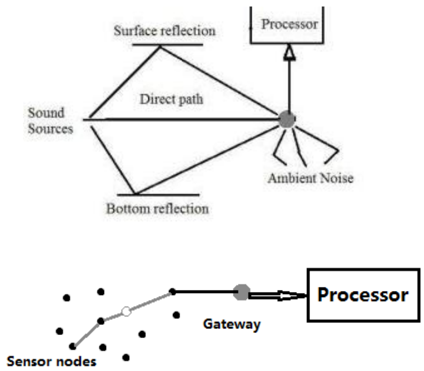

Figure 1. Wireless sensor network architecture, a) typical multi-hop WSN, b) typical Underwater WSN.

Recently, there are more and more projects and papers become interested in UWSN applications, such as acoustic communication [1], infrared wireless communication [2], and Visible Light Communication [3], etc. They have the great advantages on monitoring marine biology, deep-sea archaeology, and pollution detection and explore the life conditions of marine organisms in unknown sea-area, etc. The high frequency radio waves are strongly attenuated in water, especially in electrically more conductive salt water and the available radio modules such as Bluetooth or WLAN (802.11) operate around 2.4 GHz. In order to compensate shortages, the visible light underwater communication is a state-of-art technique, based on on-off shelf LEDs or laser LEDs. High speed transmission, high data rates and high transmission reliability are the noticeable tags of VLC system. In [5], a novel platform consists of static and mobile underwater sensor nodes and a nature inspired UWSN named as Smart Plankton is introduced in [1], where it figures out the design concept of UWSN. In order to develop an UWSN it is necessary to build an artifact that can survive, communicate, sense and cooperate in the underwater harsh and demanding environment where high pressure, corrosion, fouling and bio-erosion from colonizing organisms are threats to structure integrity and functionality. The comparison of the four communication systems is displayed as Table 1.

Table 1. Comparison between available transmission systems for underwater wireless communication

Property of medium	Radio	Acoustic	Infrared	Visible Light
Available bandwidth	Limited	Strictly limited	middle	Quite large
Transmission rate	Middle	Low	Middle	High
Range	Limited	Small	Middle	Large
Path loss	High	High	High	High
Dominant Noise	Other users	Marine organisms	Sunlight	Sunlight
Cost	High	High	Low	Low
Complexity	High	High	Low	Low
Security	High	Low	High	High

3. Current Result Achieved and Potential Research Challenges on UWSN System

In [5], a novel platform for underwater sensor networks to be used for a long-term monitoring of coral reefs and fisheries is illustrated. The nodes including both static and mobile communication point-to-point using a novel high-speed optical communication system. Moreover, it studies and shows the processes data collection; storage and retrieval work in an UWSN. A transmission protocol based on optical UWSN has been shown in [16], where the optical PHY layer structure is produced as Figure 2. Finally an experimental set-up has been created to test the optical PHY layer.

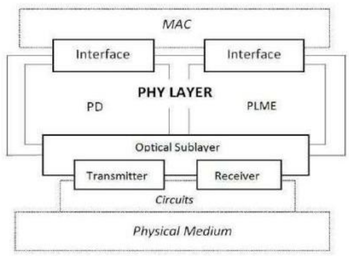

Figure 2. Optical PHY Layer structure

An experimental set-up for testing the optical communication underwater is investigated. Variability of water optical parameters and basic design considerations are further studied in [2,8]. The channel modeling shown as Figure 3 and performance evaluation using Vector Radiative Transfer Theory based on Underwater Wireless Opti-

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cal Communication is developed and simulated with a lot of waveforms both transmitted and received added. The complete research based on visible spectrum optical communication for underwater applications has been referred in [3], where both the experimental result in air and under water are presented and compared.

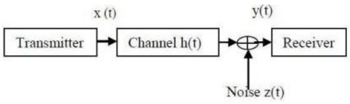

Figure 3. Additive noise channel model

1) Acoustic Communication on UWSN

Acoustic communication underwater application is also investigated in [5]. As we know, the acoustic communication is a broadcast communication system, where an XR2206 integrated circuit generates the transmitted signal. The transmission protocols are both amplitude modulation (ASK) and pulse position modulation (PPM), which can compensate the reflections. The results show that the acoustic communication is usable up to a distance of 15 m at a data rate of 41 bit/s and using PPM can achieve a higher data rate since the pulse period can be reduced. Finally the amount of data can be collected with a static sensor node over an extended period of time, depending on the maximum data storage capacity of a sensor node and the battery lifetime.

2) Optical Communication on UWSN

The following several paragraphs display us the current researches and results obtained based on optical communication using UWSN. As stated before, a mobile underwater sensor network is built in [5], where the mobile node can locate and hover above the static nodes for data mulling and can perform network maintenance functions, namely deployment, relocation and recovery. In addition, the hardware and software architecture of this UWSN is described.

Both optical communication and acoustic systems are used in [5]. The former is preferred with the potential high speed and high theoretical bandwidth, although is restricted to short-range line of sight applications. In current sensor node design [5], it has been proved each node can accumulate up to 512 Kbyte of data with a reduction time period and can realize the full duplex communication. The hardware of optical communication system used in [5] consists of a transmitter, Luxeon 5 LXHL-PM02, a 532 nm (green) LED with 10%-15% power efficiency and a receiver, PDB-C156 high speed PIN photodiode with 8 mm^2 surface areas. A green dichroic filter is imposed on photodiode to attenuate frequencies other than green. The transmission protocol is based on 4-PPM, such as NRZ, SIR, FIR and VFIR and the system is adapted by using a start pulse for each type, which can be seen from Table 2.

Table 2. Time intervals between high value pulses in our modified VFIR optical communication format.

State	Time Interval (μs)
Data bits 00	4.0
Data bits 01	4.5
Data bits 10	5.0
Data bits 11	5.5
End of Byte	6.0

The built UWSN is adapted with the optical system to determine the maximum communication range and coverage area. The results manifest that the maximum range in the clear water is longer with 8 times than that in the turbid water with the coverage area 30◦. In addition, a longer range has been obtained by applying a 60 mm F1.06 to the optical transmitter, displaying in Table 3.

Table 3. Results obtained with the UWSN system adapted with optical communication

Distance (m)	Received packets	Missed packets	Packet Success Rate
2.1	199	0	100%
4.3	199	0	100%
5.3	166	2	99%
6.4	199	0	100%
7.0	199	8	96%

The available bandwidth of underwater acoustic channels is quite limited because of absorption and dramatically depends on both transmission range and frequency. Referring to the physical layer, a large amount of studies for adapting and extending the existing link layer, routing and transport layer protocols are declared to perform a good acoustical communication.

The vector radiative transfer theory (VRTT) explains the behavior of wave propagation and scattering in a discrete random medium. It provides also characteristics of water and particles in an underwater environment, dividing them into two main parts according to the effects caused by the different materials, absorption and scattering individually.

3) Research Challenges

In this section, challenges of realizing underwater wireless sensor network based on optical communication will be presented. First, a much more efficient algorithm or protocols between PHY layer and MAC layer for underwater optical communication is not easy to figure out.

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Since the limited bandwidth of light sources (LEDs) and the channel dispersion, the data rate is limited. Referring to the cost of communication systems, typical underwater wireless sensor networks (UWSN) are expensive, however the use of such kinds of underwater manned or unmanned vehicles is quite popular for current typically communication systems. Moving to the carriers, the optical attenuation coefficients directly impacts on the performance of these communication systems, such as transmission range, error rate, and power efficiency. Besides, the water clarity changes in time, which is a permanent natural challenge, limiting the whole system performance. To build a low cost efficient UWSN using visible light communication approach is a big challenge, however, it is feasible due to the pre-distortion or pre-equalizers techniques, which can perfect compensate the non-linearity and bandwidth limited problems. More efficient modulation and demodulation techniques should be considered to the applications on UWSN to increase the data rate and mitigate the channel dispersion, such as asymptotically-clipped optical OFDM (ACO-OFDM), DC-biased OFDM (DCO OFDM) and flip-OFDM. Meanwhile the cost increases due to the high complexity of Optical OFDM. Compared with DCO-OFDM and Flip-OFDM, ACO-OFDM requires less optical power to achieve the same bit error rate but decrease the spectrum efficiency since only odd sub-carriers carry information. Due to the potential harmful effects on organism eyes, the flickers, namely inter-frame flicker and intra- frame flicker, should be mitigated by applying some possible methods, such as idle/visibility patterns, coding methods, increasing the optical clock rate, depending on what standard and modulation techniques are used. Although the advanced Optical OFDM techniques could bring the significant benefits for communication systems, the property of high PAPR may aggravate the channel dispersion and dynamics.

4. Conclusions and Future work

This paper is based on the information collection from several specific scientific papers with respect to the current researches and results of UWSN using Visible Light Communication. It consists of five sub-sections. The first section towards the general description and motivations of this paper. The basic structure of this paper has been explained at the end of first sub-section. The second one focuses on the basic introduction of VLC indoor application technique, followed by the underwater communication challenges in section III, where there is a brief introduction of WSN and the comparison of present transmission protocols underwater applications in [1,2,4-6,8]. Section IV presents the current researches, current results, and challenges of applying VLC on UWSN.

According to the current researches on UWSN, the optical OFDM with multiple transmitter systems can be used on UWSN in the future instead of using conventional methods, e.g. OOK and PPM, to compensate the dispersion. Besides, Multiple-In Multiple-Out (MIMO) technology can also be investigated on UWSN to increase the data rate. Last but not least, the dimming support should also be reminded to save the optical power due to the daytime and night. What are well known to us from VLC applications in mobile network is that light brightness control can be achieved using the continuous current reduction (CCR) and the pulse-width modulation (PWM) dimming techniques.

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