Building an Underwater Wireless Sensor Network based on Optical Communication: Research Challenges and Current Results.

Davide Anguita, Davide Brizzolara, Giancarlo Parodi
DIBE - Department of Biophysical and Electronic Engineering
University of Genoa
Via Opera Pia 11A, 16045 Genoa (Italy)
{Davide.Anguita, Davide.Brizzolara, Giancarlo.Parodi}@unige.it

Abstract

In this paper current research for an Underwater Wireless Sensor Network based on optical communication between nodes is described. Radio Frequencies are strongly attenuated in water and optical communication can be considered as a feasible solution to explore as an alternative to acoustic communication in case of short-range distance. At the moment, our work focuses on an optical Physical Layer developed considering the characteristics of IEEE 802.11 Infrared Physical Layer and the compatibility with the current IEEE 802.15.4 protocol for terrestrial Wireless Sensor Networks. This approach, that allows the interface between the optical Physical Layer and the current terrestrial technology for Wireless Sensor Networks, is a first step that will be followed by works on upper layers. In this paper, the main research challenges and current results are illustrated.

Keywords: Underwater optical communication, underwater technology, wireless LAN.

1. Introduction

One of the challenging aspects in building an efficient Underwater Wireless Sensor Network (UWSN) is underwater wireless communication. High Frequency (HF) radio waves are strongly attenuated in water: the available radio modules such as Bluetooth or Wireless LAN (IEEE 802.11), which operate in the gigahertz range, around 2.4 GHz, cannot be used underwater where, currently, acoustic communication is mainly employed [2].

In this paper the research challenges in building an UWSN based on optical communication are explored and the development of an optical communication system based on LEDs is illustrated: it can be effective because of its low power consumption, low operating voltage, long lifetime, low cost and it can establish high rate communication, as shown in [10], between fixed nodes and an autonomous underwater vehicle (up to 320 kb/s). The proposed solution is to replace the traditional infrared communication (IR), such as the one described in IEEE 802.11 standard, with visible light generated by LEDs considering the minimum absorption wavelength window of the water [8].

The described approach starts from the Physical (PHY) Layer, taking into account both the circuits for transmission and reception and the implementation of the PHY Layer used to provide services requested by the Medium Access Control (MAC) Layer. The next step will focus on the upper layers and on the hardware structure used to support the effective implementation of a prototype.

This paper is organized as follows: a brief overview of the main aspects of underwater communication, a brief illustration of the possible applications of an optical UWSN, a presentation of the proposed optical network focusing on the different layers and a report of the current results.

2. Wireless Underwater Communication

Due to the impossibility of using Radio Frequencies (RF), traditionally wireless underwater communication employs acoustic waves because sound propagates well in water and its range can be very long ($\sim$km). However, it has several disadvantages such as narrow bandwidth and latency in communication due to the slow speed of acoustic wave in water. For instance, at ranges of less than 100 m the data transmission rates of these systems in shallow littoral waters are $\sim$10 kb/s [5].

An alternative feasible solution is optical communication especially in blue/green light wavelengths, even if limited to short distances (up to 100 m) [7]. Compared to acoustic communication it offers a practical choice for high-bandwidth communication and it propagates faster in the water (2.255 x 10^8) [10].

978-0-7695-3669-9/09 $25.00 © 2009 IEEE
DOI 10.1109/SENSORCOMM.2009.79

Optical communication, however, is affected by different factors which can be summed up as follows. The attenuation of a light beam between two points can be described as in (1) where d_1 and d_2 are the positions of the points.

$$A = e^{-k(d_1 - d_2)} \left(\frac{d_1}{d_2}\right)^2 \quad (1)$$

In the first term, k is defined as $k = a(\lambda) + b(\lambda)$ and it is dependent by the wavelength: a is the term related to the absorption of water while b models the scattering which depends both on light wavelength and turbidity. The second term, instead, models the quadratic attenuation.

As is well detailed in [6], the effect of dispersion should also be included: it results from the multiple scattering of light due to particulate matter and creates the Intersymbol Interference (ISI) effect corrupting the signal waveform. Besides, ambient light can saturate the sensitive receiver if the system is utilized near the surface of the water. These elements should be taken into account in the design of a system for optical underwater communication.

Experimental tests have shown that the better wavelength lies around 420 nm (blue-violet wavelengths) [5] and that this value changes in the presence of turbidity.

3. Applications of an Optical UWSN

An optical UWSN can cover a wide range of applications in shallow water for localized operations where it can be an alternative to acoustic UWSN because of its higher data rate, lower power consumption, longer duration and lower cost. It can be particularly useful in marine natural parks and lakes or in harbors for real-time observation of underwater conditions. Some examples of its possible applications are: monitoring underwater environment; gathering data through different kind of sensors; exploring underwater biological life activity performing a highly precise, real-time and fine grained spatio-temporal sampling; supporting the use of unmanned and autonomous underwater vehicles during underwater exploration.

4. Optical UWSN

The goal of our work is to build a prototype of an UWSN based on optical communication among nodes. The idea is to adapt the current technology available for terrestrial Wireless Sensor Networks (WSNs) to the underwater world in order to address the specific characteristic of the environment. We are currently focusing on the problem of wireless physical communication. The optical PHY layer has been developed considering the characteristics of IEEE 802.11 IR PHY Layer and the compatibility with the current IEEE 802.15.4 protocol for terrestrial WSNs. This approach allows the interface between the optical PHY Layer and the current terrestrial technology for WSNs. The VHDL implementation should support the implementation of a flexible hardware module compatible with the existing WSN nodes. The adaptation of the IEEE 802.15.4 PHY Layer to optical communication, on the basis of the IEEE 802.11 IR PHY Layer, can be considered as a first step which, of course, should be followed by modifications and adaptations of the upper layers.

4.1 Circuits for Transmission and Reception

Currently we have developed a transceiver, with LEDs and photodetectors, used for point to point communication in the early test reported in Paragraph 5. Starting from this configuration the goal is to realize a wide diffuse, at limit omni-directional, transmission. The idea is to build an optical spherical or semi-spherical antenna covered with transmitters and receivers designed to maintain an optical link between nodes even when they are in relative motion. This kind of design is inspired by the optical module described in [4] for seafloor observatories. Considering also the results shown in [1] our design will take into account the problem of interference and the tradeoff between communication range and power consumption.

4.2 Trasmission Protocol

The frame format generated by the PHY Layer is inspired by the IEEE 802.11 PHY Layer for IR communication [9] and presented in Figure 2.

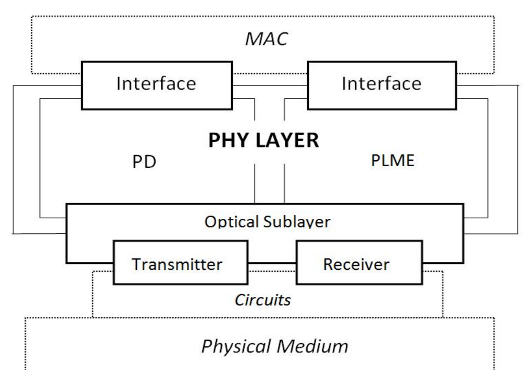

Figure 1. Optical PHY Layer structure

It consists of: a Synchronization (SYNC) field which performs signal acquisition and clock recovery; a Start of Frame Delimiter (SFD) field which contains information that marks the start of PHY protocol data unit (PPDU);

a Data Rate(DR) field which defines the data rate of the PPDU transmission (16-PPM or 4-PPM).

Preamble			Header	
SYNC	SFD	DR	Frame Length	PSDU
64 slot	4 slot	3 slot	7 bit	0-127 byte
			Transmitted by PPM	

Figure 2. Optical PHY Layer frame format

The Header consists of: a Frame Length field which specifies the number of bytes in the PHY service data unit (PSDU) field transmitted by using a 4 or 16-PPM (Pulse position modulation), a technique that keeps the amplitude, pulse width constant, and varies the position of the pulse in time in order to transmit a sequence of bits. The PSDU is the payload from the MAC layer and it is transmitted by using a 4 or 16-PPM.

The PHY Layer structure, depicted in Figure 1, is composed of different modules described in the following paragraphs.

The transmitter generates the transmission on the physical channel managing a LED circuit. It can generate a synchronization signal or a transmission signal based on PPM modulation in which bits are encoded by the position of the light pulse in time slots. The duration of the time slot is fixed by the value of the input prescaler and the modulation is a 4 or 16 PPM on the basis of the value of the input $ppm4\_16$.

The receiver manages the output of the receiver circuit. It has been designed to synchronize automatically with the transmitter baud rate: it determines how many clock cycles is the duration of the time slot chosen by the transmitter by counting 32 transitions of the input. This value is the output prescaler and it is used to decode the following PPM transmission. The receiver automatically detects the modulation (4 or 16 PPM) and performs also a clock correction in order to maintain synchronization.

The Physical Layer Management Entity (PLME) provides the layer management service interfaces through which layer management functions may be invoked.

The PHY data (PD) service enables the transmission and reception of PHY protocol data units (PPDUs) across the physical channel.

4.3 Network Architecture

The network architecture can be organized as a three-dimensional UWSN in which each node floats at a different depth trying to maintain a fixed position with a good approximation, for instance by an anchorage to the sea bed. The nodes should be designed of slight dimensions (between 15 and 20 cm), they should be densely deployed, maintaining a distance between 10 and 30 meters from each other. As detailed in the next paragraph, each node should be able to communicate, by using only a wireless optical communication link, to the neighbors and, by using a multi-hop path, to a base station placed on the water surface.

5. Current Experimental Results

An experimental set-up has been created for a preliminary test of the optical PHY layer. Two circuits have been implemented: a transmitter equipped with a blue LED, for generating an impulse of blue light and a receiver, using a photodiode, to detect the optical signal. The transmitter and the receiver have been placed together on the same board to allow for bidirectional communication between devices.

Figure 4. Experimental set-up

The preliminary experimental set-up (Figure 4) is composed of two PCs, for running the user interface, connected respectively to a Digilent S3 Board programmed with the optical PHY layer. Each Board is connected to a transmitter and receiver circuit placed in a tank (2 meters long) of clear water, Figure 5. The parameters of the transmission have been set from the user interface. A transmission and reception of data have been performed between the two devices in the tank by using optical communication generated by the optical PHY layer.

During a preliminary test, a transmission at a distance of 1.8 meters has been achieved at 100 kb/s, with a light impulse of 5 ms; the increase of the distance between the LED and the photodiode in the tank causes an increase in the BER (Bit Error Rate) and the impossibility to have a connection beyond 1.9 meters. At the moment we are planning new tests in order to perform a systematic evaluation of the BER at different distances also taking into account the dependence on water turbidity.

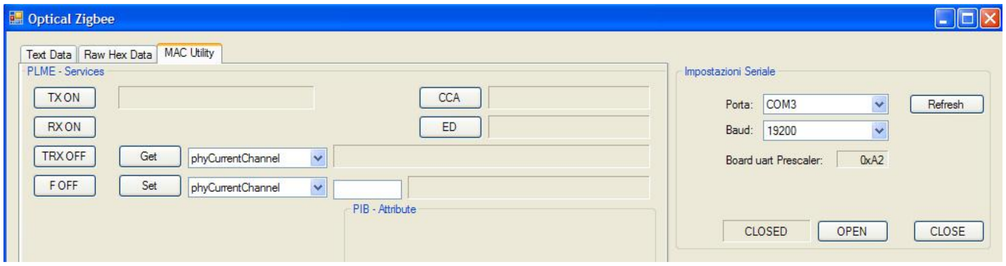

Figure 3. User interface to optical PHY Layer

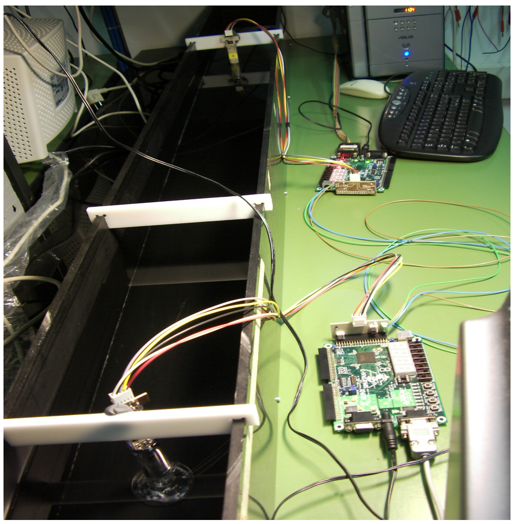

Figure 5. Tank for the experimental set-up

6. Conclusion and Future Work

In this article a first step towards the development of an optical UWSN has been illustrated. The description of the optical PHY layer and its implementation are followed by a preliminary test in order to verify its functionality. A user interface has been developed for managing the optical PHY layer implementation on a Digilent Spartan 3 Board.

The next step in our work will focus on the implementation of the a block to obtain a wide diffuse or omnidirectional optical signal and on the implementation of network nodes by adding upper layers on the basis of the compatibility with current terrestrial technologies.

New technologies developed for our optical UWSN will be very useful for innovative underwater devices, such as Smart Plankton (www.smartplankton.org) [3].

7. Acknowledgments

We thank Mr. Giorgio Carlini (DIBE - University of Genoa) for his support in circuits implementation.

References

[1] J. Akella, C. Liu, D. Partyka, M. Yuksel, S. Kalyanaraman, and P. Dutta. Building blocks for mobile free-space-optical networks. In *Second IFIP International Conference on Wireless and Optical Communications Networks. WOCN 2005.*, pages 164 – 168, 2005.

[2] I. F. Akyildiz, D. Pompili, and T. Melodia. Underwater acoustic sensor networks: research challenges. *Ad Hoc Networks (Elsevier)*, 3:257–279, 2005.

[3] D. Anguita, D. Brizzolara, A. Ghio, and G. Parodi. Smart plankton: a nature inspired underwater wireless sensor network. volume 7, pages 701–705, Oct. 2008.

[4] N. Fair, A. Chave, L. Freitag, J. Preisig, S. White, D. Yoerger, and F. Sonnichsen. Optical modem technology for seafloor observatories. *OCEANS 2006*, pages 1–6, Sept. 2006.

[5] J. Giles and I. Bankman. Underwater optical communications systems. part 2: basic design considerations. *IEEE Military Communications Conference. MILCOM 2005.*, pages 1700–1705 Vol. 3, Oct. 2005.

[6] S. Jaruwatanadilok. Underwater wireless optical communication channel modeling and performance evaluation using vector radiative transfer theory. *IEEE Journal on Selected Areas in Communications*, 26(9):1620–1627, December 2008.

[7] L. Lanbo, Z. Shengli, and C. Jun-Hong. Prospects and problems of wireless communication for underwater sensor networks. *Wirel. Commun. Mob. Comput.*, 8(8):977–994, 2008.

[8] J. Smart. Underwater optical communications systems part 1: variability of water optical parameters. *IEEE Military Communications Conference. MILCOM 2005.*, pages 1140–1146 Vol. 2, Oct. 2005.

[9] R. Valadas, A. Tavares, A. Duarte, A. Moreira, and C. Lomba. The infrared physical layer of the ieee 802.11 standard for wireless local area networks. *IEEE Communications Magazine*, 36(12):107–112, Dec 1998.

[10] I. Vasilescu, K. Kotay, D. Rus, M. Dunbabin, and P. Corke. Data collection, storage, and retrieval with an underwater sensor network. In *Proceedings of the 3rd international conference on Embedded networked sensor systems: SenSys '05*, pages 154–165, New York, NY, USA, 2005. ACM.