Underwater Laser sensor network: A New Approach for Broadband Communication in the Underwater

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Abstract: In this paper a new approach for the underwater sensor network based on the blue-green laser has been proposed. We describe the application of the underwater sensor network in the undersea exploration, and discuss the difficulties in the traditional the underwater acoustic sensor network. A basic of prototype of underwater laser sensor network has been advanced, which include the architecture of laser sensor node and protocol stack for underwater laser sensor network. Based on the advantages in the underwater laser communication, the underwater laser sensor network has great potential perspective in the undersea exploration.

Key-Words: underwater sensor network, blue-green laser, laser communication

1. Introduction

Today the terrestrial wireless sensor networks already get great advancement, however the underwater sensor network still poses some difficulty problems. In the early, the undersea exploration is based on the individual undersea robot. The efficiency of exploration in this approach is very low, and it is difficult for an individual robot to explore the given sea. In order to improve the efficiency of exploration in the undersea environment, multi-robots must collaborative to explore the given sea. When multi-robots collaborate with each other to explore the undersea, the sensors in the robot will communicate with sensors in the other robot. All those sensors will makeup an underwater sensor network. This underwater sensor network is deemed to enable applications for oceanographic data collection, pollution monitoring, offshore exploration and tactical surveillance [1, 2].

It is important for undersea exploitation to dependent on the underwater sensor network. However, it is great difficulty for radio propagation in the underwater. For the most frequencies, the radio can just propagate a very short range in the sea. For example, the Berkeley Mica 2 Motes, the most popular experimental platform in the sensor networking community, have been reported to have a transmission range of 120cm in underwater at 433MHz by experiments performed at the Robotic Embedded System Laboratory at the University of Southern California [3]. In fact, some radio waves can propagate at long distance through conductive sea water only at extra low frequencies (30-300Hz), but the large antennae and high transmission power are required, which is difficulty for underwater sensor nodes. In order to overcome the obstacle for the radio propagation in the sea water, the traditional approach for underwater communication is based on the acoustic waves. On the other hand, some underwater optical communication methods based on the LED have been brought forward, but these communication methods can be used in a very short range (In general, it is about 1 to 10 meters) [4, 5]. In this paper we present a new broadband underwater sensor network based on the blue-green laser, which can be communicated in a long range.

The remained of this paper is organized as follows. In Section 2 we investigate the traditional underwater acoustic sensor network and the

challenges in this approach. In Section 3 we introduce the blue-green laser communication in the sea water, and then we picture the architecture of laser sensor node and protocol stacks for the underwater blue-green laser sensor network. In Section 4 we compare the underwater acoustic sensor network and the underwater blue-green laser sensor network.

2. Underwater Acoustic sensor network

In traditional, the acoustic communication has been developed for the underwater network since World War II. With the exploitation in the sea, more and more underwater acoustic network projects have been carried out. For example, the Georgia Institute of Technology, Massachusettes Institute of Technology, University of Princeton and many other universities already developed some underwater acoustic sensor networks [6, 7, 8]. However, the underwater acoustic signal is influenced by path loss, noise, multi-path, Doppler spread and high variable propagation delay. And the direction of underwater acoustic communication also affect the acoustic link, which means that the different propagation direction has different propagation characteristics, especially with respect to the time dispersion, multi-path spread and delay variance. Hence, the underwater acoustic channel is a temporal and spatial variable system, which make the available bandwidth limited and dramatically dependent on both range and frequency.

Hereafter some disadvantage factors have been listed that influence acoustic communications in order to state the challenges posed by the underwater channel for underwater sensor networks.

- High delay:
  The signal propagation speed in the underwater acoustic channel is about 1.5×10^3 m/sec, which is five order of magnitude lower than the radio propagation speed (3×10^8 m/sec). The large propagation delay seriously reduces the

throughput of the system considerably, and also determine the unstable in the underwater control network system.

- Limited bandwidth
  The acoustic band underwater is very little due to absorption, so most acoustic communication system operate below 30KHz. As a result, the bandwidth of underwater acoustic channels operating over several kilometers is about several tens of kbps, while short range system over several tens of meters can reach hundreds of kbps.

- High bit error rate
  Because of path loss, multi-path fading, Doppler spread, and noise (from man and ambient) in the underwater acoustic channel, there is a large bit error rate in the underwater acoustic channel, which is on the order of 10^{-2}-10^{-5} . In order to prevent from the serious error in the communication, the special ARQ (Automatic Repeat Request) techniques and FEC (Forward Error Correction) techniques must be adopted, which improve the complexity in the underwater acoustic sensor network.

- High energy consumption
  The power consumed in the underwater acoustic communication is more than in the terrestrial radio communication, because more power is consumed in the complex signal processing at receivers to compensate for the impairments of the channel.

Affected by the above factors, the current underwater acoustic sensor network just provides the limited communication for different application, which can realize the information communication among the different sensor nodes without any quality of services. At the same time, the above factors cause the efficiency in the underwater acoustic sensor network to be very low and the complexity of protocol stack to be high.

3. Underwater Laser Sensor Network

In order to overcome the disadvantages in the underwater acoustic sensor network, we present a

new approach for underwater sensor network.

3.1 Blue-green laser in the underwater communication

Most of laser can not penetrate through the sea due to be absorbed by the sea, but the blue-green laser (the length of wave is about $470 \sim 570nm$) has the minimum energy fading in the sea, whose fading rate is about 0.155~0.5db/m. Hence, the blue-green laser can propagate from several hundreds of meters to kilometers in the sea, and this feature of blue-green laser in the sea is said the window effect. Based on the window effect of blue-green laser, some submarine communication systems have been developed. In these communication systems, the blue-green laser is a collimated laser beam, which should be aimed at the submarine when sender tries to communicate with submarine [10, 11].

In this paper, we present to use the blue-green laser as the new communication approach for underwater sensor network. Because the sensor nodes in the sea are always in the dynamic, it is difficulty for sensor nodes to aim each other. We bring forward not to use the collimated laser beam, in contrast, we suggest using the diffused laser beam for underwater communication. For example, when the diffused angle is $30°$, the diffused laser beam can cover a large area. Even the receiving sensor node excurses a little distance, it can still receive the communication signal. The process of sending and receiving can be seen in the Fig.1.
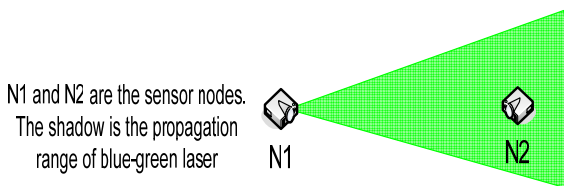

Fig.1 the process of sending and receiving for the underwater blue-green laser sensor network

3.2 Underwater laser sensor architecture

The typical internal architecture of a node in the underwater acoustic sensor network is used for reference, and then we picture the internal architecture of a node in the underwater blue-green laser sensor network in the Fig.2. It consists of the sensor, the sensor interface circuitry, the memory, the power supply, the CPU and the blue-green laser modem. The CPU gets the data in the sensor through the sensor interface circuitry, and then the CPU can story the data in the memory, process the data in itself, and send/receive the data by controlling the blue-green laser modem.
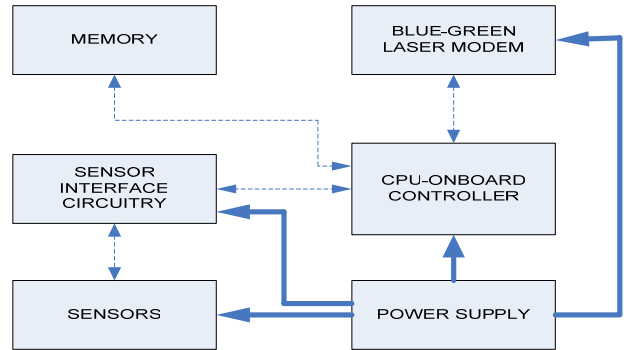

Fig.2 Internal architecture of a node in the underwater blue-green laser sensor network

3.3 Protocol stack for the underwater laser sensor network

The protocol stack for the underwater laser sensor network should consist of physical layer, data link layer, network layer, transport layer and application layer functionalities. Considering the critical underwater environments, the underwater laser sensor network is different with the terrestrial sensor network. The protocol stack should also include the energy management plane, 3D topology management plane, QoS management plane and the mobile management. The architecture of protocol stack for the underwater laser sensor network is pictured in the Fig.3.
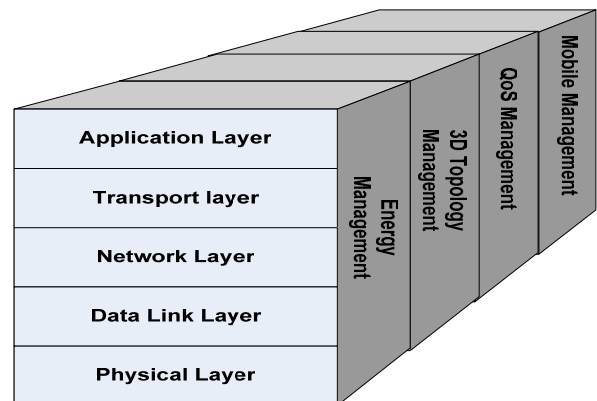

Fig.3 The architecture of protocol stack for the underwater laser sensor network

In this architecture, the energy management plane is responsible for network functionalities aimed at minimizing the energy consumption. The 3D topology management plane is responsible for controlling and adjusting the underwater network topology according to the requirement from the underwater exploration. The QoS management is responsible for the quality of data transmission, which should ensure the transmitted information is satisfied for the application requirement. The mobile management is responsible for the sensor node moving, which should ensure the moving of underwater sensor node is reasonable. In other words, the sensor node can automatically move to overcome the excursion caused by the stream, and the sensor node will ensure the laser communication can not be interrupted because of mobility.

4. Conclusion

With the exploitation in the undersea and development in the communication techniques, the underwater sensor network is gradually becoming a hotspot in the wireless communication. A new approach for the underwater sensor network has been proposed, which is based on the blue-green laser. The characteristics of underwater laser sensor network and underwater acoustic sensor network have been compared in the following table.

Table 1 Characteristics of underwater laser sensor network and underwater acoustic sensor network

	underwater laser sensor network	underwater acoustic sensor network
Delay	little	high
Bandwidth	Several hundreds of kbps per kilometer	Several tens of kbps per kilometer
Bit error rate	low	high
Energy consumption in communication	low	high
Propagation distance	1~2 kilometers	Several tens of kilometers
Propagation speed	3×10^8 m/sec	1.5×10^3 m/sec

According to the comparison in the table 1, the underwater laser sensor network has great perspective in the undersea exploration. The architecture of underwater laser sensor node and the protocol stack for the underwater laser sensor network have been proposed in this paper. Based on the above architecture and protocol stack, a research for the underwater laser sensor network is ongoing now, and the result of this research will promote the development in the underwater sensor network.

References

[1] J. G. Proakis, E. M. Sozer, J. A. Rice, and M. Stojanovic. Shallow Water Acoustic Networks. *IEEE ommunications Magazine*, pages 114–119, November 2001.

[2] E. M. Sozer, M. Stojanovic, and J. G. Proakis. Undersea Acoustic Networks. *IEEE Journal of Oceanic engineering,* OE-25(1) pages: 72–83, January 2000.

[3] M. Stojanovic, Acoustic (underwater) communications, in: J.G. Proakis (Ed.), *Encyclopedia of Telecommunications*, Wiley, New York, 2003.

[4] I. Vasilescu, P. Varshavskaya, K. Kotay, and D. Rus, Autonomous Modular Optical Underwater Robot (AMOUR): Design, Prototype and Feasibility Study, *International Conference on Robotics and Automation,* Barcelona, Spain, April 2005.

[5] Krill: An Exploration in Underwater Sensor Networks Vasilescu, I.; Kotay, K.; Rus, D.; Overs, L.; Sikka, P.; Dunbabin, M.; Chen, P.; Corke, P.; Embedded Networked Sensors, *2005. EmNetS-II. The Second IEEE Workshop* on 30-31 May 2005 Page(s):151 – 152

[6] I. F. Akyildiz, D. Pompili, and T. Melodia. Underwater Acoustic Sensor Networks: Research Challenges. *Ad Hoc Networks Jounal (Elseviier),* March 2005.

[7] http://www.mit.edu/people/millitsa/research.html

[8] http://www.princeton.edu/dcsl/aosn/

[9] L.W.Wright. Blue-green lasers for surmarine

communications, Naval Engineers Journal, 1983, 95(3), pages: 173~177

[10] T.F.Wiener, S.Karp. The role of blue-green laser systems in strategic submarine communication. *IEEE Trans.Commun.*, 1980, Com-28(9) pages:1602~1607