Experiment Research on Underwater Acoustic Sensor Network

Wei Liang, Haibin Yu
Shenyang Institute of Automation, Chinese Academy of Sciences
Shenyang 110016, China
weiliang@sia.ac.cn

Bangxiang Li,Hualiang Zhang,Jieyin Bai,Jianying Zheng
Shenyang Institute of Automation, Chinese Academy of Sciences , Shenyang 110016, China
Graduate University of Chinese Academy of Sciences , Beijing 100039, China

***Abstract*—Experiment is the effective research means. In this paper, an experiment platform for underwater acoustic sensor networks(UASNs) is designed and developed, which serves as the testing and evaluating system of UASNs and is convenient, flexible and scalable... In this platform, an automatic testing language is proposed, which can support performance testing of point-to-point underwater acoustic communication without interference of researcher. Moreover, end-to-end networking experimentation of UASNs can be done with this platform. Lots of research works on UASNs are done based on this platform and a great deal of experiment data on underwater acoustic communication and networking are accumulated.**

Keywords- underwater acoustic sensor network; communication; experiment

I. INTRODUCTION (HEADING 1)

Underwater Acoustic Sensor Networks (UASNs) a kind of measuring and controlling network system consisting of unmanned or autonomous underwater vehicles (UUVs/AUVs) and sensor nodes that have sensing, communication computing and moving capabilities. UASNs, which have the features of distributed space, distributed time and distributed function, is a typical autonomous and intelligent system which can independently accomplish specific tasks depending on the changing environment over a given volume of water.

UASNs are envisioned to enable applications for oceanographic data collection, pollution monitoring, offshore exploration, disaster prevention, assisted navigation and tactical surveillance applications[1]. Multiple unmanned or autonomous underwater vehicles(UUVs/AUVs), equipped with underwater sensors, will also find application in exploration of natural undersea resources and gathering of scientific data in collaborative monitoring missions. To make these applications viable, there is a primary need to enable underwater communications among underwater devices.

Acoustic communications are the typical physical layer technology in underwater networks. Wire communications are difficult to deploy and are unsuitable for moving. In fact, radio waves suffer from such high attenuation, while optical waves are affected by scattering and high precision in pointing the narrow laser beams. Acoustic wireless communications enable the UASNs[2]. However, the complexity of underwater environment and Acoustic communications are the challenges to UASNs. Hence, UASNs have become a hot research topic.

The unique characteristics of the underwater acoustic communication channel, such as limited bandwidth capacity, high propagation delays and low reliability are time-variant, space-variant and frequency-variant[3]. Moreover, the ocean environment is dynamic and complex. Hence, theory analyses and precise simulation is difficult for UASNs. Therefore, experiment becomes the main research means of UASNs.

A few experimental implementations of underwater acoustic sensor networks have been reported in the last few years. The Front-Resolving Observational Network with Telemetry(FRONT) project relies on acoustic telemetry and ranging advances pursued by the US Navy referred to as 'telesonar' technology[4]. The Seaweb network for FRONT Oceanographic Sensors involves telesonar modems deployed in conjunction with sensors, gateways, and repeaters, to enable sensor-to-shore data delivery and shore-to-sensor remote control. Researchers from different fields gathered at the Monterey Bay Aquarium Research Institute in August 2003 and July 2006 to quantify gains in predictive skills for principal circulation trajectories, i.e., to study upwelling of cold, nutrient-rich water in the Monterey Bay, and to analyze how animals adapt to life in the deep sea. However, experiment research on UASNs is elementary and seldom work on developing platform for UASNs is reported according our knowledge.

In this paper, we design and develop a physical experiment platform for UASNS. The experiment platform consist of system control module, sensing module, automatic communication testing module, networking module and evaluation module, which can complete automatic point-to-point communication performance tests and end-to-end networking experiments. This platform serves as the testing and evaluating system of UASNs, which is convenient, flexible and scalable. Based on this experiment platform, a lot experiments are made and a great deal of data on acoustic communication and networking are accumulated.

The remainder of this paper is organized as follows. In Section 2, we introduce the design and implementation of the UASN experiment platform. And in Section 3, we show some of experiments results. We draw the main conclusions in Section 4.

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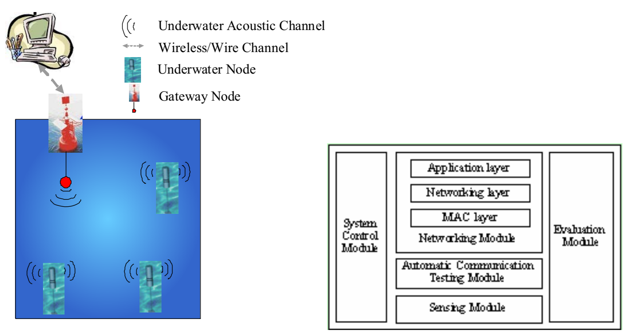
II. PLATFORM DESIGN AND IMPLEMENTATION

An experiment platform was developed. In this section, the design and implementation detail is described.

A. *Platform Architecture*

Experiment system for UASNs is composed of one gateway node and multiple underwater nodes, as shown in Figure 1(a). The gateway node consists of underwater transducer, surface station and network adapter. Underwater transducer can support underwater communication, while surface station support terrestrial communication. Network adapter implements the end-to-end networks. And transducer is connected with surface station via a special interface and surface station is connected with network adapter via serial interface. The underwater node consists of sensor, underwater acoustic telemetry modems(ATM) and a network adapter. Sensors are responsible for collecting the environment information and ATM can support underwater communication. Sensor and ATM are connected with network adapter through serial interfaces. Multiple underwater/gateway nodes can establish a UASN network according to requirement.



(a) Hardware (b) Software

Figure 1. Experiment system of UASNs

The software module is based on above hardware devices and consists of system control module, sensing module, automatic communication testing module, networking module and evaluation module, as shown in Figure 1(b).

- Control module completes functions controlling the system via control instruction. Control instruction can be divided into system instruction and protocol instruction. System instruction can manipulate and control experiment system, including automatic upload/download/reset of drivers, start/stop/pause of testing platform etc. Relatively, protocol instruction includes protocol selection, parameter setting and so on, which conveys instruction and information to all layers of protocol programs through standard inter-process communication and inter-thread communication. To simplify the operation processing of experiment, this module adapts remote controlling mechanism and can supply the capability of centralized and uniform information processing.

- Sensing module is responsible for collecting sensing data and processing collected data simply.

- Automatic communication testing module is the basic environment of acoustic communication tests. With the proposed automatic testing language, automatic testing of communication performance between two acoustic modems can be made. Hence, the operation of acoustic modem performance testing is simplified and man-made control factors in testing are decreased.

- Networking module is the kernel part of this platform, which implements some typical protocol stack of UASNs. This module realizes the special access protocols, routing protocols and application protocols. Each layer supplies uniform interface in order to give facilities for developing new protocols. These protocols can be configured by application.

- Evaluation module realizes the performance evaluation system. This module is responsible for real-time data statistics during the system operation process and statistics processing of testing criteria after testing.

B. *Implementation of Main Modules*

In view of paper length, the implementations of some main modules are introduced below.

1) Automatic Communication Testing Module: To testing the performance of acoustic communication, executing modem AT instruction one by one is necessary that will spend too much manpower and time. Moreover, costs of experiment of UASNs on ocean/lake are very expensive. Hence, an automatic testing module of acoustic modem is designed and developed, in which multiple items of AT instruction can be executed by a simple encapsulated instruction. This module can improve the testing efficiency and save the experiment cost.

We design a kind of language that can executing automatic testing, called ATM Automatic Testing Language(ATM-ATL). This language mainly includes four kinds of instruction set as follows.

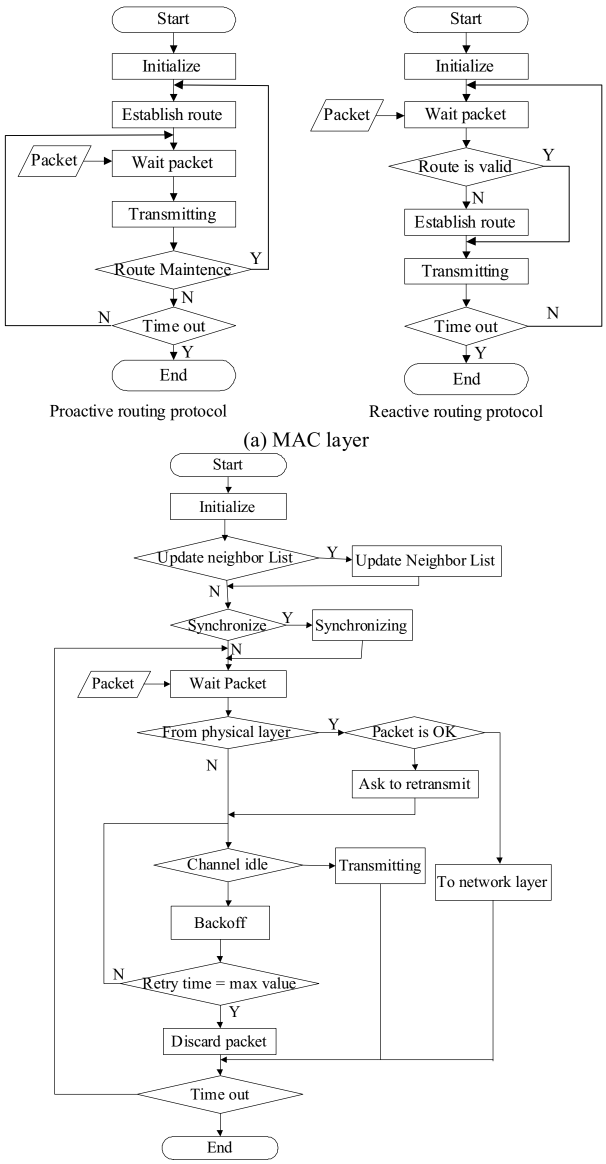
- Simple instruction set: includes the standard AT instruction set.

- Multiple instruction set: is similar as the single circulation sentence in advanced programming language, its form is 'for variant(1)=A~B step k [do instruction(1)]', which means that the instruction(1) is executed when the value of variant(i) changes from A to B with step k. The instruction(1) belongs to Simple instruction set and optional. When instruction(1) is omitted the instruction is used to setup properties. The default step is 1.

- Composite instruction set: is similar as the multiple circulation sentence in advanced programming language, its form is 'for variant(1)=A_1~B_1 step k_1 for variant(2)=A_2~B_2 step k_2 ,.., for variant(n)=A_n~B_n step k_n do instruction(1) instruction(2) ,.., instruction(m)'.

- Special instruction set: is used for controlling and management tests. For example, instruction '*stop*' is used to clear the instruction buffer and cancel all released instruction, instruction '*sleep*' is used to set the interval time of low energy monitoring status.

2) Networking Module: A configurable protocol stack is developed to support networking based on acoustic communication, as shown in Figure 1(b). To establish a universal platform, the basic network protocols are integrated into the protocol stack.



(b) Network layer

Figure 2. Figure 2. Networking Module

- Network Layer Upon receiving PDU from application and MAC layer, the module carries out route selection for packets. This module may be used to test and analyze many kinds of different route algorithms in a way of comparison, for instance, FLOODING, DSR, AODV and so on. Its detail implementation frame is shown in Figure 2(a).
- MAC Module This module receives packer from network or physical layer and allocates wireless channel. This module may be used to simulate channel access protocol of data link layer and test many kinds of MAC protocols, such as Aloha, non-persistent CSMA, 1-persistent CSMA and p-persistent CSMA etc. The detail implementation frame of MAC Module is shown in Figure 2(b).

3) Evaluation Module: According to the process, the evaluation module includes three sub-modules. The first is randomly generating tasks for experiment in term of the preset system load. The second is collecting the experiment results from the programs of protocol stack. The last is calculating the statistic results of testing criteria. These three sub-modules are inter-independent and can respectively operate after defining uniform criteria. The following performance criteria are used in our platform.

- SNR is the ratio of unanamorphic signal strength from signal source to the noise strength.
- ERR is the count of error bit in a packet.
- Multi-path delay is the influence time of multi-path effect.
- Successful transmission rate is the ratio of successful transmission to the total transmission.
- Point-to-point communication delay is the time that point-to-point packet transmission spends.
- Throughput is the amount of information transmitted successfully per time unit.
- Network load is the amount of information transmitted per time unit.
- Energy dissipation is the amount of energy dissipated and can reflect the network lifetime.

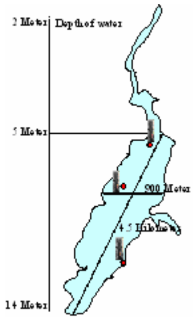
III. Experiments

A. *Experiment Setup*

Our experiments were made in Qipanshan reservoir, whose position is longitude 123.4 degrees east and latitude 41.56 degrees north. The area is about 5.04 km2 and the depth is from 2m to 14m. The scenario of experiment is shown in Figure 3(a).

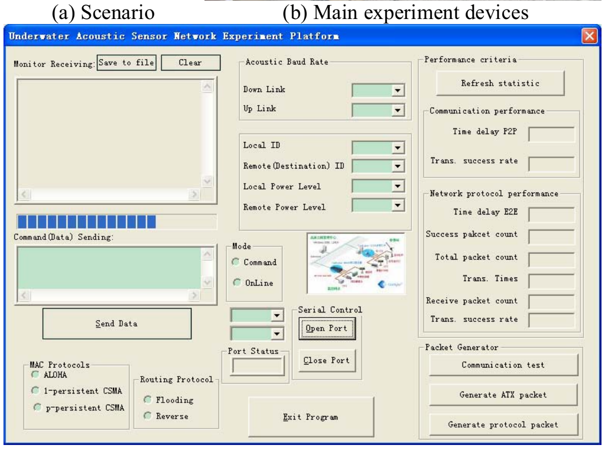
We have deployed three nodes, as shown in Figure 3(b). The first one is consist of Benthos Acoustic Telemetry Modems ATM891 and ATM408, and it is stationary gateway node. The second one is Benthos ATM885 Modem and work as an underwater relay node. And the third one is an underwater sensor node and is consist of Benthos ATM885 and CTD sensor measuring water temperature, saltiness and depth. Relay node and sensor node are floating with boat. The modem work in frequency band 9-14kHz and average transmission energy is 40W. The sampling interval is 30s.

The main interface of experiment platform is shown in Figure 3(c).



(a) Scenario

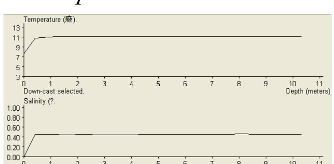
(b) Main experiment devices



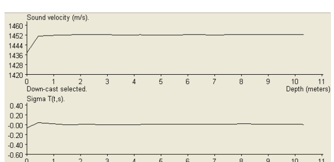
(c) Main interface of platform

Figure 3. Experiment Setting

B. *Experiment Results*

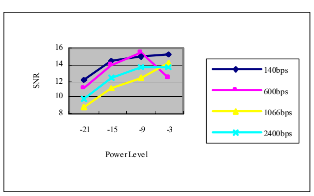


(a) Temperature and salinity

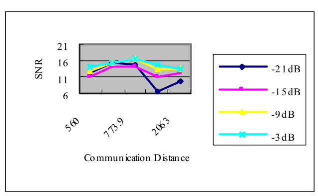


(b) Sound velocity

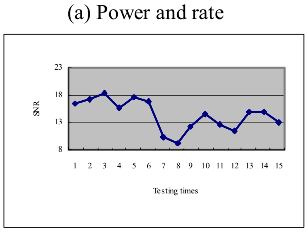
Figure 4. Sensing data



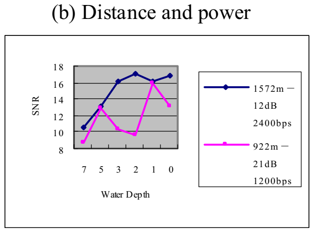
(a) Power and rate



(b) Distance and power



(c) Time



(d) Depth

Figure 5. Communication experiment results

Great deals of experiments are made based on this platform. The measured data of CTD are shown in Figure 4.

- Communication experiments: Figure 5(a), (b), (c), (d) is respectively the results of different transmission power level and communication rate, different distance and transmission power level, different time, different water depth.
- Networking experiments: The compared results are shown in Figure 6 with different MAC and routing protocols. The distance between two nodes is about 1600m. The communication rate is 600bps. The data packet is 112 Byte and control is 16 Byte. The relative moving speed between nodes is from 0 to 1.5m/s.

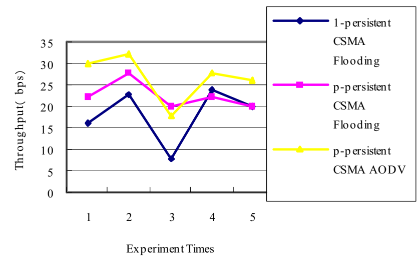


Figure 6. Networking experiment results

IV. CONCLUSIONS

Experiment is the main and effective research means, whereas research on experiment platform and experiment results is seldom because the research cost is very high. In this paper, an experiment platform for UASNs is developed. And lots of research works on UASNs are done based on this platform. However, further experiment research and protocol designing for UASNs should be processed.

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