The design and experiment of a software-defined acoustic modem for underwater sensor network

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Abstract- **In this paper, the design scheme and system implementation of a compact, low-cost, energy-efficient, real-time, software-defined acoustic (SDA) modem for underwater sensor network are described. The hardware and software performance of the SDA modem are presented by the underwater experiment results of different underwater communication and networking method using the same modem.**

I. INTRODUCTION

Underwater sensor networks (USN) have the potential to enhance our capability to many applications in the ocean for a variety of purposes: such as oceanographic data collection, ocean sampling, environmental and pollution monitoring, offshore exploration, disaster prevention, tsunami and seaquake warning, auxiliary navigation, distributed tactical surveillance, and mine reconnaissance[1][2].

For the building of underwater sensor networks, one of the most challenging tasks is the design and development of real-time acoustic modem for the communication among the sensor nodes in the USN. The framework for the design and implementation of software definable radios is suitable for acoustic modem[3]. The ability to provide a software definable solution that can map different acoustic communication and networking applications with the same hardware.

In the recent years, several designs and development about SDA modem are described, but only several laboratory test results are introduced, and real underwater experiments by SDA modem are unseen[4][5].

In this paper, we will describe architecture of a SDA modem, specifications for this SDA modem, and several underwater experiment results for different acoustic communication and networking application implemented on the same modem.

II. SDA MODEM DESIGN

In this part, the system design consideration of SDA modem is described. As Fig.1 shown, the hardware modules for SDA modem system are divided into four parts: receive and processing module, transmit module; energy module, sensor module.

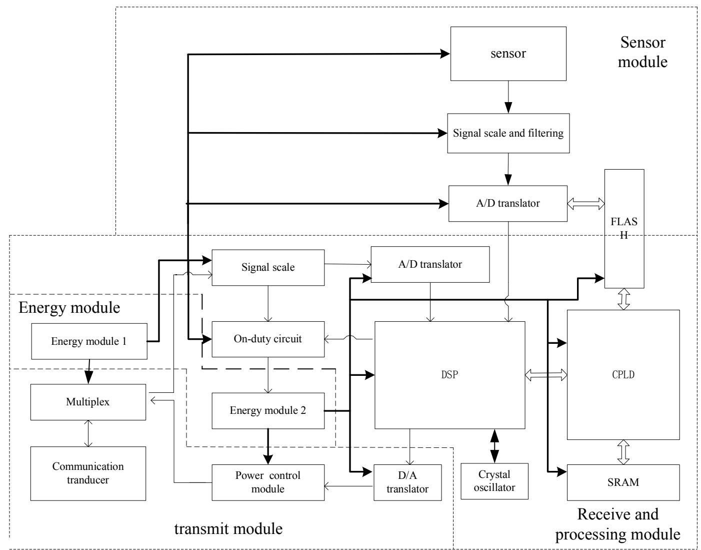

Fig.1 the modules for SDA modem

Receive and processing module, is designed to receive and detect the network packets, demodulate and analysis packets, process and modulate the sensor collected data.

The digital signal processor (DSP) is the key part of this module. Most of SDA modem's data processing work is finished by the DSP. Therefore, a low-cost energy-efficient DSP is considered to select. In the SDA modem system, a fixed-point digital signal processor Blackfin 561, which is able to change the CPU working frequency with the different workloads, is selected to work.

The analog input has a user-programmable gain stage and low-pass anti-aliasing filter, with a 12-bit selectable sampling A/D, typically sampling at 160 kHz for.

A high-precision on-board real-time clock provides a high -precision signal for timing application such as navigation and synchronization.

Transmit module, is designed to transmit out data packets. It consists of communication transducer, power control module and D/A converter.

The power control module is the key part of this module.

It consists of a single channel class-D power amplifier to drive the projector, and FPGA-based control circuit to manage transfer parameters smartly. The class-D amplifier topology was chosen due to its superior efficiency characteristics and simplicity of matching to various transducers. So the power control module is efficient and easily modifiable for use under various signal frequency/ bandwidth, projectors and vehicle power systems.

Energy module, is designed for energy supplement for the whole system. It consists of two energy modules.

The energy module 1 supplies the low voltage modules, such as DSP, acoustics transducer, on-duty circuit and sensor module. On-duty circuit works continuously with a very low-power, shuts down power supply for other modules completely in a very low-power sleep mode.

The energy module 2 supplies the high voltage module such as power amplifier. high instantaneous current

With this division of work in energy module, we can make different power cost scheme for different energy modules such as lower power consumption for the energy module 1 and high energy efficient for the energy module 2.

Sensor module, is designed for data collection, scale and cache, consists of sensors, signal scale and filtering circuit, A/D translator and cache flash and so on.

For different purposes, different types of sensor can be selected. Some are low sampling meters, such as thermometer and salimeter. Some are high sampling meters, such as hydrophone. Therefore, the multi-sampling A/D translator and circuits were considered by system design.

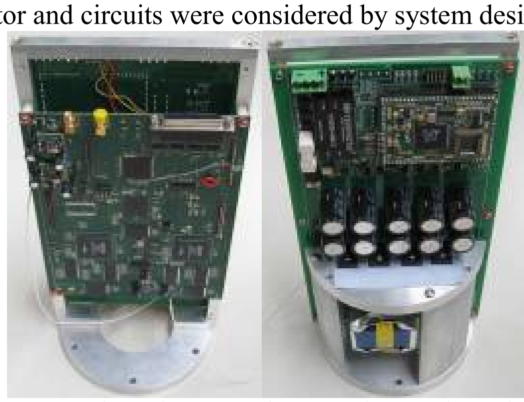

Fig.2 the compact electronic system of SDA modem: receive and processing module (left), transmit module (right).

Receive and processing module and transmit module are the two core parts of the whole SDA modem system. With a compact and modular circuit layout, the electronic system of SDA modem is small-footprint (6.5×8.6 inch) as shown in Fig.2. With the choice of low-power electronic elements and circuit optimization especially for the transmit modular, the dissipation of energy in the electronic system is reduced. And the table.1 shows several typical specifications for SDA modem.

Table.1 the Specifications for SDA modem system

Specifications	performance
Size	6.5×8.6 inch
Transmit Module Power(without high voltage)	1.8W
Transmit Electrical Efficiency	95%
Max Transmitted Acoustic Source Level	190dB
Transmit Power(SL=180dB)	21W
Receive Amplified Gain	88dB
Receive Electrical Noise	8uV
Receive Power	24mW
Processing Power	0.56W（600MHz）
Idle Power	8mW

III. UNERWATER EXPERIMENT

For testing the performance of SDA modem and protocols based on it, we had organized two experiments on the Qiandao Lake, Zhejiang, China in 2008 and 2009. The Qiandao Lake is an artifact lake with 50 to 60 meters depth and many underwater rolling hills. As shown in Fig.3, two sound speed profiles are collected near the tested ship in the winter of 2008 and 2009. This environment is similar to the typical shallow water environment.

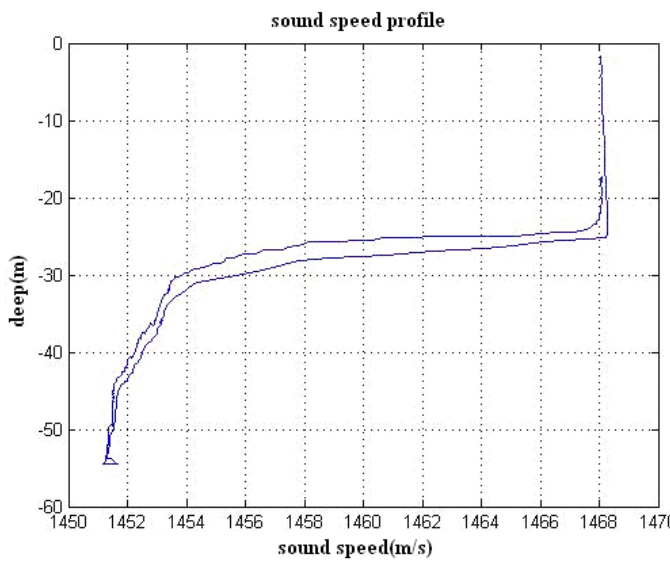

Fig.3 sound speed profiles at Qiandao Lake in general

The experimental network nodes equipped with SDA modem were shown in Fig.4. By the modular design, SDA modem could be work at the different frequency-band with simple acoustic transducers match. At Qiandao'08 and '09, the

SDA modems were operated in a bandwidth of 10 kHz at a center frequency 25 kHz.

Fig.4 sensor network nodes equipped with SDA modem

Through software-defined implementation, SDA modem can be worked conveniently with different digital modulation methods and different networking protocols, easily modified by these technique's parameters according to status on site.

By RS422/232 interface, SDA modem can be connected with the GUI on PC station. The user is able to monitor the data transmission and network topology, and change the parameters such as transmitted power or received gain on line. Fig.5 shows one on-site snapshot result for high speed real-time image transmission at Qiandao'09. In this snapshot, the real-time transmitted results are display at the upper right corner comparing with the original picture. It had no error in 32678 bit per frame with 8km range and 8kbps transmitted bit rate.

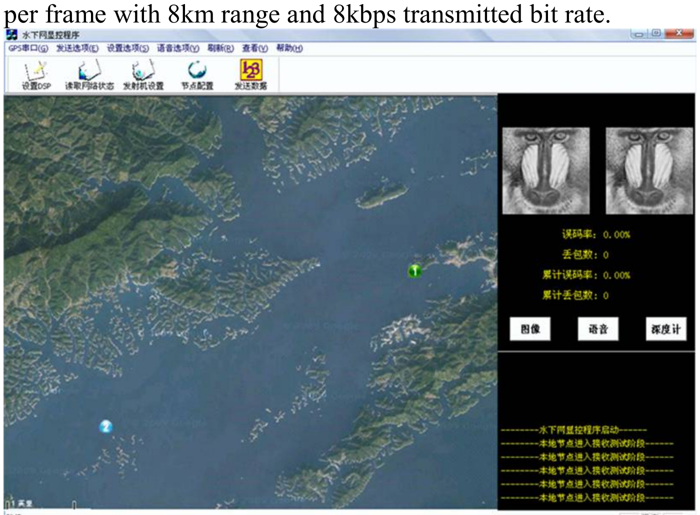

Fig.5 the snapshot about high speed real-time image transmission between 8 km with SDA modems

As shown in table I, we present the results of node-to-node acoustic communication used by SDA modem with different modulation, coded and rate of bit in Qiandao'09. For moderate-speed transmission, by using 8kbps QPSK coherent modulation and 1/2 convolution code, the maxim transmission range reached 10km and meanwhile the bit error rate was less than 10-5 at the 180dB source level. For low-speed transmission, the tested range reached 5km and the bit error rate was less than 10-5 by 1.14kbps DSSS with 7-length Gold sequences and 1/2 convolution code at 175dB source level. For high-speed transmission, 20kbps OFDM with channel codes had the performance of 1km range and 10-5 bit error rate.

Table.2 the performance of node-to-node acoustic communication in Qiandao'09

Modulation	Source code	Bit rate (kbps)	Range (km)	BER
QPSK	Conv.	4	5	8.1×10e-5
QPSK	No code	8	5	2.4×10e-4
QPSK	Conv	8	5	1.4×10e-5
QPSK	Turbo	8	5	0
QPSK	Conv	8	8/10	7.7×10e-6
QPSK	Conv	16	5	6.7×10e-4
DSSS	Conv	1.14	5	6.6×10e-6
OFDM	No code	20	1	2.1×10e-3
OFDM	Conv	20	1	6.0×10e-5
OFDM	Turbo	20	1	0

At Qiandao'08 and '09, we chose two physical protocols for stability of networking, the chief one was 8kbps QPSK, the other one was 1.14kbps DSSS. For building one distributed self-organized network by SDA modem, two up-layered protocols were developed. The RTS/CTS based MACA/CA protocol was chosen for MAC[6]. The AODV protocol and N-for-one SARQ protocol[7] was chosen for networking and transport. Especially，Both protocols were adjusted to suit for underwater sensor network.

By these protocol stacks, we finished Short-range ad-hoc networking with seven nodes and Mid-range with four nodes at Qiandao'08 and '09. One gateway centralized topology and peer-to-peer distributed topology were tested. The longest distance for data transmission was 4.1km with multi-hop and node-to-node interval was 2.6km. The initial time of self-organized networking is 9 seconds with no-collision and 12 seconds with collision.

At Qiandao'08 and '09, the different types of data including image, voice and the sensor collected data (depthometer), were real-time transmitted in the building network. As shown in Fig.5 (on-site photograph), one centralized underwater network consist of four nodes was built quickly, and the data of image were real-time transmitted packet-by-packet from node 2 to node 1(gateway). As shown in Fig.6(on-site photograph), one peer-to-peer underwater network was self-organized and all network topology was displayed on the GUI, the collected data with depthometer in node 3 were transmitted to node 4 and the value of depth measurement was close to the value of actual deployment.

Fig.6 the on-site photograph about Ad hoc networking at mid-range with four nodes and real time image transmission

Fig.7 The photograph about Ad hoc networking at mid-range with four nodes and real time image transmission

IV. CONCLUSION

In this paper, we reported the design and development of a low-cost low-power software-defined acoustic modem. The different acoustic communication and networking prototypes were able to be developed on generic and modular hardware. The performance of this modem for node-to-node data transmission and self-organizing networking were tested by the underwater experiments. These results confirm that the modem has the capability of running for difference applications of underwater sensor networks.

ACKNOWLEDGMENT

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