An Implementation of Acoustic-based MAC Protocol Multichannel Underwater Communication Network

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Key Words : AUV, Acoustic, Underwater Communication, Throughput, Modulation, Propagation delay

Abstract

This paper proposes a new efficient system design strategies for the acoustic-based underwater multiple modem and media access control protocol. The system aims to establish the acoustic-based communication network of an underwater vehicles for deep sea mining, which ensures a certain level of maximum throughput regardless of the propagation delay of acoustic and allows fast data transmission through the acoustic-based multiple channel.

A media access control protocol for integrated communication network and it's acoustic-based communication modems that allows 'peer-to-peer' communication between a surface mining plant multiple underwater system is designed, and the proposed media access control protocol is implemented for its verification.

Furthermore, a proposed design strategies which make it possible to control the multiple vehicle for an underwater mining is presented in this paper.

I. Introduction

Recently, due to the increasing interests in deep sea mining, all possible efforts to development of underwater unmanned vehicle such as AUV (Autonomous Underwater Vehicle) or underwater robots are exerted. The underwater systems are autonomously navigated by using the acoustic-based digital communication system, which receives the multiple control systems from surface ship and sends the underwater information to surface ship or plants[6].

Furthermore, a new strategies which make it possible to control the multiple vehicle for underwater duty working by the surface plants have been attempted. For an approach to implementation of the system, it is inevitable to establish acoustic-based underwater digital communication network to

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exchange the information between a surface plants and multiple vehicle in underwater.

This paper proposes the design strategies of the high-bit rate underwater acoustic-based digital data telemetry links which include the subsystems such as transducer with pre-amplifier, modulation/demodulation, encoding/decoding system, and also proposes the new media access control protocol for underwater vehicles network. The basic schemes of underwater digital communication network are similar to existing wired/wireless local area network in a view of communication distance and broadcasting media. But, media access control protocol such as CSMA(Carrier Sense Multiple Access , [5]) for an existing network is intend to communication network by using the high speed media such as electric signal, and thus it may introduce the reduction in throughput when appling the protocol to underwater communication network. The CSMA media access control protocol is highly specialized to produce a high throughput when packet transmission times is 100 times bigger than propagation delay. But, propagation delay of underwater acoustic network is usually bigger than packet transmission time, and maximum throughput decreases dramatically[2].

The application level services for underwater network include transferring the control signals from surface ship, the underwater images from underwater systems and the data transmission from sensors. In particular, it is required that the network speed must be about 10-50kbps for transmitting the image data in real-time. But, service speed range of underwater communication system is only 1-10kbps due to the limited sound speed in underwater. Therefore, the low speed channel is restricted to the various data transmission in real-time. And it becomes more difficult for multiple underwater systems to use a single channel as a common media.

In this paper a media access control protocol for underwater communication network that allows 'peer-to-peer' communication between a surface ship and multiple underwater systems is designed, and the proposed control protocol is implemented for its verification.

Ⅱ. Acousti-based Underwater Telemetry Links System

Recent developments in acoustic-based underwater telemetry system enable real-time contact with underwater sensors, vehicles, and other instruments, offering novel ocean observational capabilities that may change future oceanographic operations. Acoustic transmission is an attractive option for underwater communication only because radio frequency(RF) and optical energy are severely attenuated in underwater environment, whereas acoustic energy propagates very well[9].

AUV(Autonomous Underwater Vehicle) for the deep sea mining occasionally requires human guidance or the ability to inform others of its situation. An issue of growing interests in AUV working area is that of cooperating AUV, mining collector and surface plant, where several vehicles or plants perform complementary actions is order to accomplish a singular task. A acoustic-based underwater telemetry links system is needed for transmitting the data such as control command, image information, emergency information and status information in underwater environment. To accomplish the task, acoustic-based underwater telemetry links system was implemented, which include the subsystems such as transducer with filter and preamplifier, underwater acoustic modem, signal modulator or demodulator and digital signal processing module as shown in Fig. 1. The system design schemes is as follows.

At the digital signal processing unit, a sensor signal is converted to digital data by D/A (Digital to Analog) converter. Then, digitized sensor data is saved at a memory of DSP processor, and the saved data in DSP memory is transmitted to main control computer by RS-232C connection.

A acoustic modem transmits the data such as image data, status information(position, direction, speed, power etc.) and a measured data to the surface ship. For the transmitting data, $\pi/4$ QPSK(Quadrature Phase Shift Keying) modulation technique(Proakis, 1983) which has a high performance in the limited frequency bandwidth is used in acoustic modem. A directional transducer which has the center frequency 50 kHz and frequency bandwidth 10 kHz is used in this system.

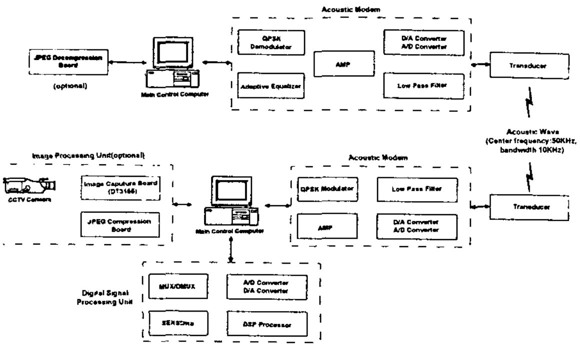

Fig. 1 A system configuration of acoustic based underwater telemetry links system

At the surface ship, acoustic modem modulates the received data using the $\pi/4$ QPSK demodulation technique, and decompress the image data using the JPEG board. So, the operator of surface ship can monitor the status of underwater system, image information and measured sensor data through the display equipment.

Ⅲ. Limitations to Underwater to Access Control Protocol Design

1. Limitation Physical Layer

Protocol design conditions of underwater acoustical communication network are quite different from those of terrestrial-based RF system or microwave system and render microwave-based protocols inefficient or useless for underwater applications. The predominant difference is to the one way propagation time to packet duration, and this propagation delay has a dramatic impact on the protocol selection. For example, in the two underwater network deployed to date, this relative propagation delay falls in range of 1-100 times the packet size. For terresterial-based system with the same geographical coverage(100-1000 square km) and the packet length, this propagation delay is give orders of magnitude smaller, due to the ratio of propagation velocities of light and sound[10].

This significant difference makes propagation time an important componet in the network delay of underwater system, and suggests a sparing use of handshaking, acknowledgements, and retransmissions between acoustical modems. In addition, the relatively infrequent access of modems to the network renders fixed-time or fixed-frequency assignment schemes inefficient for underwater acoustical schemes, as each sub-channel would be poorly utilized.

Another consideration is the geographical diversity of underwater modems. This divisity produce a large variation in one-way propagation time and preclude of use of golbal synchronization, which is required for all time-sharing or time-slotted protocols.

The acoustic telemetry channel has other features that must be considered in the design of efficient network protocol. The ocean is a broadcast acoustical channel the occupies a rather narrow frequency band and transmission other interface with each other at a receiver. Therefore, the efficient flow of data packets along a changing topology of communication links is the primary goal of a network protocol. Historically, the two measures of protocol efficiency have been network throughput(the average rate of successful packets) as well as the average transmission delay incurred by a packet.

2. Limitation to Level Layer Services

Application high level layer services of an underwater communication as the above mentioned mainly consist of access flow control signals, sensors data and positioning data for the underwater mining system. The traffic information for an image transmission out of these signals requires 10~50 kbps bit rate[1]. But, the acoustical transducers used in physical layer can support 1~10 kbps bit rate. The low speed transmission acoustical bit rate makes limitation to transmit the real time measured data and flow control signals. Furthermore, it is difficult for one channel to use the common channel in multi-media.

Therefore, multiple channels with different frequency bandwidth for each others should be utilized to transmit the service in high level layers through the low bit rate channel. And also, a underwater network designer synthesis a protocol that strikes a reasonable balance between throughput and expected delay. Because the throughput and average packet delay of any protocol are heavily dependant on the physical properties of both the transmission media and the transceiver, a protocol that is efficient for one scenario may perform quite poorly in another.

Ⅳ. Design of Access Flow Control Protocol

1. Frame Design of Access Flow Control Protocol

The basic function of an access flow control protocol is to transfer frames from the higher sub-layer of logical link control to the destinations. To carry out the processing access flow control, access flow control function to use the common transfer channel for each other stations and error detection function which is occured by collision to other stations among the transfer channels are required. CRC(Cyclic Redundancy Code) bit pattern for the error detection and distinguisher frame to indicate the start and end are to be inserted.

The design results for the access frame format compiling with the above mentioned condition is shown in Fig. 2. The frame format is similar to SDLC(Synchronous Data Link Control) frame forma.t As the SDLC protocols is the bit oriented protocol, zero insertion for a distinguishing frames when the five '1'(high) is consecuitively assigned in the information field.

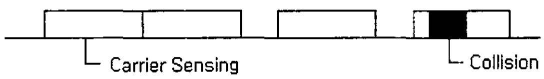

Fig. 2. Frame format of MAC protocol

2. Multiple Acoustical Channel-based Tx and Rx Frame

Acoustical underwater communication network environment with which is to be dealt in this system has the multiple stations and multiple acoustical channels to use the stations. Each station can transmit frames to destination through the one channel out of these multiple channels.

This paper deals with the protocol design to capitalize on the knowledge of the round-trip propagation times of the ocean-bottom nodes(AUV or seabed robotics) and to utilize fully the acoustical channels without utilizing the round-trip propagation times, a collision free data channel schedule data channel packets corresponding to the concepts, designed protocol is as follows.

2.1 Carrier sensing

The carrier sensing transition algorithm as shown in Fig. 3 operates when overflow which accumulate the idle time for each channels is occured by the increasing flag. If the carrier sensing is detected, the flags for the related channel is set to '0' and timer operates again. The carrier sensing for the transmitting channel is detected as bit unit.

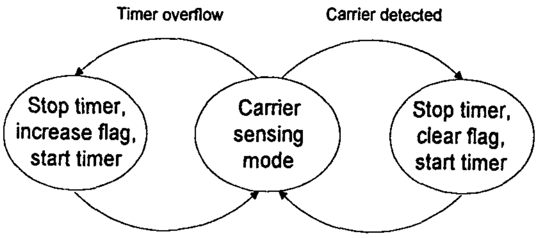

Fig. 3 The carrier sensing static diagram

2.2 Receiving frame

The receiving frame mode in the carrier sensing mode as shown Fig. 3 is returnned to carrier sensing mode after transmit the 'ACK' signal to other related station and process the received frame, as the results og frame error. If there is a frame error in other station, 'NAK(Nagative Acknowledgement)' signal is transmitted to other related station and returned to carrier mode after canceling received frame. The receiving state transition diagram is shown in Fig. 4.

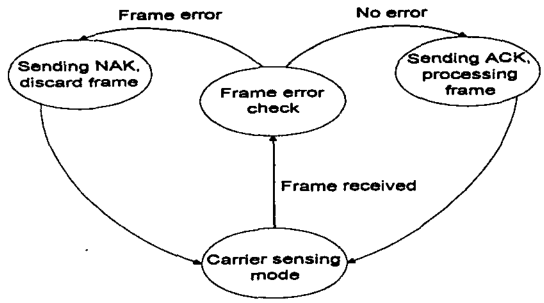

Fig. 4 The receiving state transition diagram

2.3 Transmission frame

The transmitting frame is established by requesting to frame transmit signal in compling with the Fig. 5 transition procedure. For the transmitting frame, one

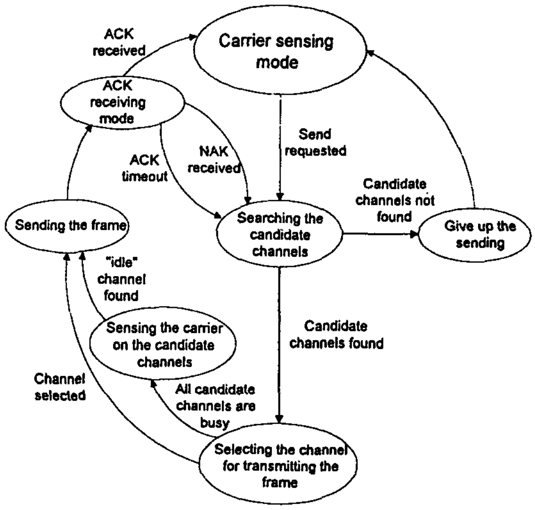

Fig.5 The sending state transition diagram

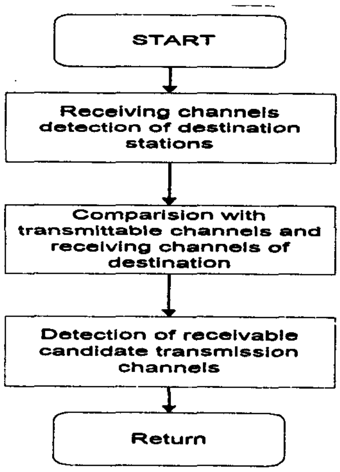

Fig. 6 The procedure for searching candidate channels

acoustical channel among them should be selected. At the first stage for it, the candidate channel which is possible to transmit the frame in own station and to receive the frame in destinate station is made a search. The procedure for searching candidate channel is shown in Fig. 6 and candidate channel for the frame transmitting is selected by procedures as shown in Fig. 7, that is compared with accumulating the 'idle' time. The transmitting frame channel is selected as the longest 'idle' time channel and returned to 'ACK' receiving mode after

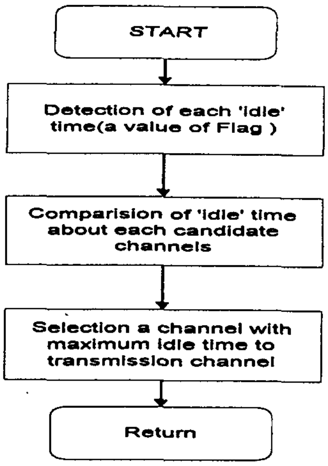

Fig.7 The procedure for selecting the sending channel

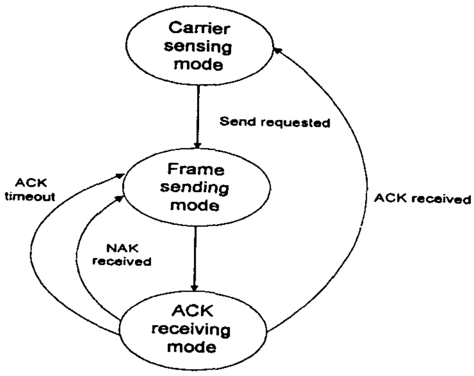

Fig. 8 The state transition diagram for receiving ACK

finishing the frame transmission procedure. If there is no 'idle' channel in this procedures, the carrier sensing is made a search for the related candidate channels and is returned to 'ACK' receiving mode with the transmitting the frame in 'idle' channel when the 'idle' channel detected.

2.4 Error control

The error control method in this paper is deployed to 'stop and wait ARQ(Automatic Repeat reQuest)' as shown in Fig. 8. In the method, the station is returned to 'ACK' receive mode after transmitting the frame. The 'ACK' signal is received in 'ACK' mode, and returned to carrier sensing mode. If 'ACK' signal is not received or 'NAK' signal is received, transmitted frame is retransmitted as the previous explained procedures.

V. Conclusions

This paper proposes the design strategies of the high-bit rate underwater acoustic-based digital data telemetry links which include the subsystems such as transducer with pre-amplifier, modulation/demodulation, encoding/decoding system, and also proposes the new media access control protocol for underwater vehicles network. The system aims to establish the acoustic-based communication network of an underwater vehicles for deep sea mining, which ensures a certain level of maximum throughput regardless of the propagation delay of acoustic and allows fast data transmission through the acoustic-based multiple channel.

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Furthermore, a proposed design strategies which make it possible to control the multiple vehicle for an underwater mining is presented in this paper. The implemented protocol ensures the maximum throughput regardless of propagation delay in underwater ultrasonic communication channel, and makes it possible to transmit the data with high bit rate through multiple channels.

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