GT^2 – Reduced Wastes Time Mechanism for Underwater Acoustic Sensor Network*

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Abstract. Recently, development of original technologies and connection technologies of UW-ASN for data transmission in underwater environment has been accelerated. Since propagation delay is inevitable at acoustic communication in underwater environment, the transmission time tends to be increased as network radius increases. Besides, there are difficulties of Multiple Access Control (MAC) service, which supports to avoid the collision and maintain reliable transmission condition. In this paper, a new scheduling method was proposed to eliminate the effect of interferences in a channel by taking both Gain-time and Guard-time into consideration.

Keywords: Underwater Acoustic Sensor Network (UW-ASN), MAC Scheduling, Gain-time and Guard-time (GT^2).

1 Introduction

There are many different features in Underwater Acoustic Sensor network comparing with radio networks. One of those features is its narrow bandwidth caused by lower speed and very large propagation delay [1].

MAC should play a role of managing and controlling channels, which are shared by many nodes, to avoid collisions and to maintain reliable transmission condition. Under poor transmission environment, such as Underwater Acoustic Sensor network with narrow bandwidth and higher error rate, development of better MAC algorithm has been a critical issue. It is because the energy consumption of the communication system becomes larger and the cost of computing time and memory is also increased in case of re-transmission [2]. Besides, the condition of underwater acoustic transmission is much more inferior comparing to radio network in air [1]. In conclusion, MAC study plays a key role in its overall system performance.

Recently, many new scheduling and synchronization methods have been proposed to solve the problem of large propagation delay and transmission variance which is proportional to distance. Slotted floor acquisition multiple access (FAMA) was

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proposed to reduce excessive waste of control packets [3]. MAC for Underwater Wireless Acoustic Network (UWAN) was proposed to solve synchronization problems and minimize the length of hand-shake procedure for non- synchronized ad-hoc UW-ASN [4][5]. Many research works, however, were the non-centralized contention-based multiple access control mechanism for ad hoc sensor networks. In underwater acoustic networks, three network topologies were proposed: centralized topology, single hop distributed topology and multi-hop topology[6][[7][8]. This paper discusses Master Driven mechanism which is classified into MAC mechanism for centralized topology.

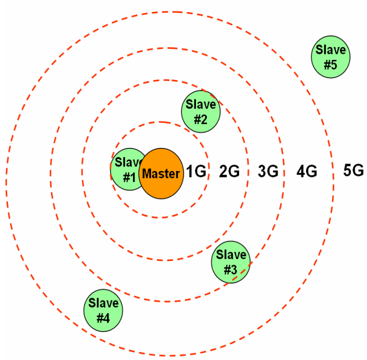
Common problem of underwater environment is a propagation delay regardless of what kinds of MAC are used. That is, the problem of propagation delay is not related to communication protocols. Generally, a Guard-time has been applied based on the maximum propagation delay of the network. However, GT^2 TDMA MAC scheduling technique proposed in this paper can be applicable to clustered networks. The proposed method is to increase the network efficiency by determining the moment of data transmission and data receipt adaptively taking the Gain-time and the Guard-time into consideration. In chapter 2, acoustic transmission model and the relationship between frequency bandwidth and the length of transmission data were investigated. In chapter 3, GT^2 transmission method was described. Finally, conclusion in chapter 4.

2 Underwater Environment and Acoustic Data Transmission

Analysis of marine environment is related to many parameters. For example, the speed of acoustic wave propagation is 1,500 meter per second in case of 20‰ of salinity and 22℃ of water temperature while the speed decreases to 1,450 meter per second in case of 6℃ of water temperature. As for water pressure, the acoustic wave speed increases as water pressure increases. In this paper, Mackenzie's Nine-terms algorithm [9], which is one of theories of sound speed, was selected to setup propagation model for definitions of marine environment parameters. Besides, transmission loss and noise model were selected for modeling errors caused by attenuation and various noises.

Table 1. Bandwidth and Distance

Distance	Range [km]	Bandwidth [kHz]
Very Long	1000	< 1
Long	10 ~ 100	2 ~ 5
Medium	1 ~ 10	≈ 10
Short	0.1 ~ 1	20 ~ 50
Very Short	< 0.1	> 100



Distance Group list

Node ID	Group ID
Slave #1	1G
Slave #2	2G
Slave #3	3G
Slave #4	4G
Slave #5	5G

Fig. 1. Distance Group

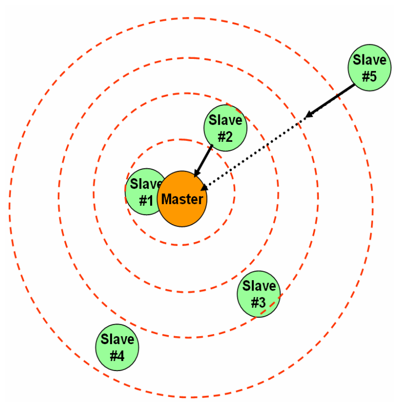


Fig. 2. An example of Distance Group

Acoustic wave can propagate farther as water depth increases and the wave speed determines the bandwidth. Table 1 shows relations between bandwidth and range (i.e. distance).

Acoustic wave speed in underwater condition is 1.5 x 10^3 m/s on the average which is faster by 4~5 times in air. Besides, the speed increases as water temperature, salinity and water pressure increase. In general, 1℃ of temperature rise causes 3 m/s of wave speed increase. If water depth increases by 100 meters, the speed increase is 1.7 m/s. As for the effect of salinity, 1 ppt(precipitate) rise of salinity causes 1.3 m/s of speed increase. Generally accepted equation of acoustic wave speed calculation is as follows

$$c=1449 + 4.6T - 0.55T + (1.39 - 0.012T)(S - 35) + 0.017Z$$

Where T is temperature in Celsius, S is salinity in p.s.u.(practical salinity unit), Z is water depth in decibar, c is speed in m/s.

3 GT^2 UW Transmission Model

3.1 Distance Group (DG)

DG is a transmission group classified by the distance between Slaves and Master. It is a concept introduced to differentiate propagation delay and guard band from DG. DG is known to all nodes in the network during network initialization procedure. Each node assigns adaptive time slot using node's order and group information. Figure 1 shows an example of DG. The concept of DG is based on the assumption that long distance transmission and the value of propagation delay affects Gain-time and Guard-time sufficiently. In addition, since deploy of nodes is relatively sparse, it is possible to applicable to most underwater acoustic sensor networks.

As shown in Figure 2, Slave #2 and #5 have difference DG of 2G and 5G respectively. That is, Slave #2 is closer to Master. In this case, data transmitted by two nodes do not collide even if theses two nodes start transmission simultaneously since each other's distance to Master is different. Therefore, it is not efficient at all for Slave #5 to start transmission after Slave #2 finishes its transmission. In the proposed TDMA MAC scheduling, the concept of Gain-time, which is based on each nodes' distance to Master, is introduced. Based on the information of distance between Master and Slaves which can be obtained during network initialization procedure, each node is given its DG. The allocated DGs will be used for operation and allocation of time. Besides, since the Guard-time is also determined based on the value of DG. Figure 3 is a simplified diagram of GT^2 MAC technique showing the following two procedures. More detailed procedures are described in Table 2 and 3.

Table 2. Network Initialization procedure

(1)	*Master broadcasts Advertisement periodically*
(2)	*Slaves respond by sending join request message to Master*
(3)	*Master sets up the information of Distance Group information by using the information of Propagation Delay which were obtained during procedure (1) and (2)*
(4)	*Master broadcasts network configuration finished message with DGL to over all network.*

Table 3. TDMA Scheduling procedure using GT^2

(1)	*Master broadcasts Beacon frame, in which the information of reservation time slots is contained, for gathering the information of Slaves. At this moment, if there is any informa tion received from slave(s) in the very previous round, Ack to the information is also tran smitted. (Another research on this procedure is progressing as separate research item)*
(2)	*Slaves who received the Beacon transmit data during their assigned time.*
(3)	*After the corresponding round, a join procedure of new nodes, a periodic network reconfi guration procedure or setting-up new information requested by the network system can be conducted.*

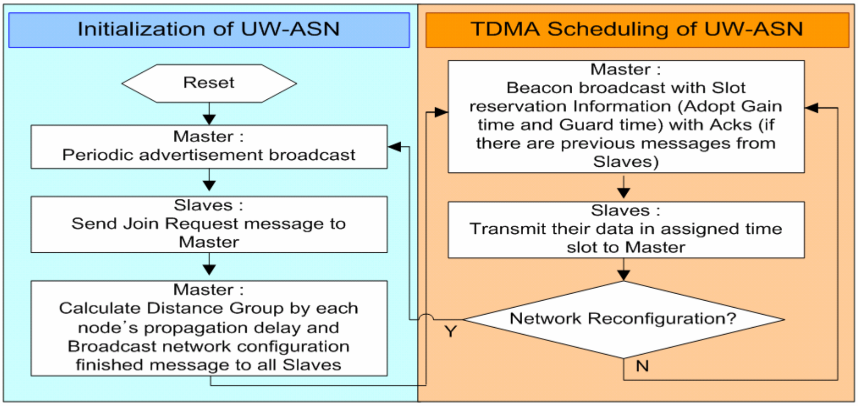


Fig. 3. Simplified Flowchart of GT^2 MAC

A distance-based concept Gain-time, which can be deduced during network initialization procedure, is introduced to give DG to each node. In the proposed GT^2 MAC Scheduling Scheme, therefore, it is intended that the concept of Gain-time according to distance interval is introduced and DG is given to all nodes on the basis of distance information between Master and Slaves which can be obtained during network initiation procedure. Besides, Guard-time is set by DG values. It is because as the distance increases the variation width with respect to transmission completion time also increases.

In proposed concept, all time units related to network operation is set to time slot. The size of unit time slot is already set in all underwater sensor network systems and determined on the basis of the distance and the frequency. It is a well known fact that the bandwidth is dependent on the center frequency so it is natural that the bandwidth is related to the length of time slot [9]. Time of underwater sensor network systems is calculated in slot unit and expressed as an integer value which can be an exact standard consequently.

3.2 Gain-Time and Guard-Time (GT^2) Mechanism

In underwater sensor network systems, there is room for scheduling which is based on gains calculated from the delay time caused by media characteristics. In TDMA transmission procedure, DG of the previous node enables transmission delay time to be estimated. By referring to the delay time, the Gain-time can be estimated. The estimated Gain-time is calculated by unit of time slot and can be used during transmission. If the distance is not enough for obtaining Gain-time, 0 is set to Gain-time. In case of a network with large radius, which means the case of a long transmission distance, the gain calculated from Gain-time is also increases. Figure 4 shows an example of Gain-time and Guard-time.

Master puts the information of the assigned time slot and the transmission sequence of Slaves into Beacon and transmits the Beacon to the Slaves. Slave #2, #5 and #1 transmit data according to the pre-defined scheduling sequence and the pre-assigned time slot. In Figure 4, slave #2 and #5 obtained the Gain-time of 1 and 4 time slot, respectively. Slave #1 could not obtain any Gain-time. On Master's side, the probability of collision is avoided by assigning enough Guard-time when receiving data transmitted from each slave.

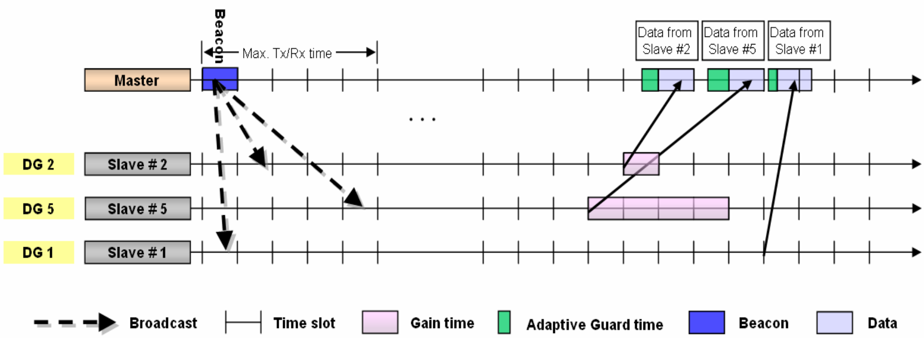


Fig. 4. An example of Gain-time and Guard-time

Guard-time is set taking the variation of transmission, which is possibly caused by irregular variations of underwater transmission environment, into consideration. It also can be set to be proportional to the distance between transmitting nodes. Since time variance is dependent on distance, it is required for Guard-time for listening to be adaptive against the distance between transmitting nodes. Figure 4 shows an adaptive Guard-time as well.

4 Conclusion

The proposed GT^2 TDMA MAC Scheduling method is applicable to Master/Slave structure cluster based networks. Taking that the majority of ocean and underwater sensor networks aim for exploration and monitoring into consideration, the proposed method is expected to contribute to development of more efficient MAC scheduling.

For future study, mathematical models will be developed for calculation of the proper size of time slot according to a network radius, the number of sensor nodes, frequency bandwidth and the packet length. Besides, using the model, exact Gain / Guard-time will be calculated and compared with the conventional methods. And the performance of the proposed method will be evaluated based on the comparison results.

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