Multi-channel MAC Protocols for Underwater Acoustic Sensor Networks

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I. Introduction

Medium Access Control(MAC) protocol is quite important to the performance of underwater sensor networks(UWSNs). Recently, much research work has been done on the design of new MAC protocols for UWSNs to improve throughput and energy efficiency [1]–[3]. All these work is for the single-channel network scenario. However, the fast development of underwater acoustic communication technologies enables multiple acoustic channels to be used concurrently in underwater networks. For example, "AquaNetwork" modem from DSPCOMM can provide multiple parallel CDMA channels to the upper layer. It is well known that most MAC protocols for single channel can not work well in multi-channel environments and thus, new multi-channel MAC protocols are needed here for high performance [4], [5].

Multi-channel MAC protocols have been recently investigated for UWSNs [6]–[8]. And it is shown that Multi-channel schemes can achieve higher throughput and energy efficiency than the single-channel schemes. However, most of the previous work on multi-channel MAC protocols for UWSNs does not model and analyze the collisions behavior and other related MAC layer issues for the long-delay underwater environments. And to our best knowledge, there are no related work to compare different multi-channel MAC protocols for underwater networks.

In this work, for the first time, we analyze and compare the performance of three different multi-channel MAC protocols, namely, 1) Random multi-channel aloha access protocol; 2)Multi-channel protocol with RTS/CTS on a dedicated control channel; 3)Split phase multi-channel access protocol. Because of the space limit, all analysis process is skipped here.

II. System Analysis

A. Random multi-channel Aloha access protocol

This is the simplest multi-channel MAC scheme. It works as follows. As shown in Fig. 1, channels are divided into one control channel and multiple data channels. Every node continuously monitor the common control channel. When a node wants to send a data packet, it first selects one data channel randomly from the available data channels. And then, it will send one control packet on the control channel to inform the receiver which channel that it will used for this transmission. And after that, it will send out its data packet on the select data channel without delay. No handshaking processes are required for this protocol. This scheme is similar to the scheme in [7]

This scheme is based on pure ALOHA scheme and does not need any time-consuming handshaking process such as RTS/CTS exchange. It is simple and easy to be implemented. Our analysis shows that its performance is not affected by the long-delay feature of underlying acoustic channels. When the average packet length packet is long and the input traffic density is large, packet collision probability in the network will soar because of its random feature. Correspondingly, its performance will degrade significantly. This scheme is suitable for the network scenario with light traffic and short data packet.

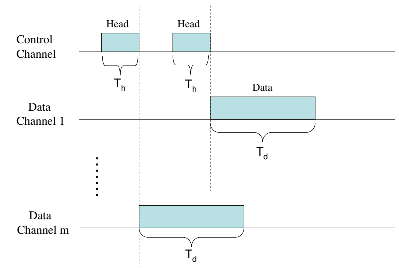

Fig. 1. Random multi-channel Aloha access protocol

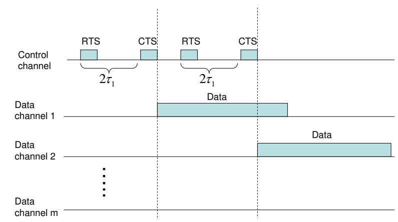

Fig. 2. Multi-channel with RTS/CTS on a dedicated control channel

B. Multi-channel with RTS/CTS on a dedicated control channel

As shown in Fig. 2, this scheme works as follows. Channels are divided into one control channel and multiple data channels. Every node continuously monitors the control channel. The sender with packets to send first sends out a RTS (Request-to-Send) message on the control channel. The RTS message should include the sender's id, the receiver's id, the available channel set and the packet length. After correctly receiving a RTS message, the intended receiver will select one channel randomly from the available channel set based on its network condition. Then, it will respond with a CTS (Clear-to-send) message to inform the sender the selected data channel and tune to listen on this channel. After receiving this CTS message, the sender will send out its data packet on the selected data channel. Through this RTS/CTS process, overhearing neighbors will get to know this transmission event and the used data channel

Because of the non-negligible propagation delay, the channel allocation and communication process can no longer be modeled by a markov process as that in the terrestrial radio network [5]. In our analysis, two virtual markov processes are proposed which can be served as the upper and lower bounds for the network's performance. Our simulation results show that the proposed bounds are quite tight in most cases for the long propagation-delay network environment.

For this scheme, the RTS/CTS exchange on the control channel shortens the collision region of every data packet, which greatly reduces the collision probability and improve

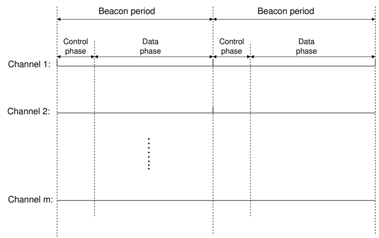

Fig. 3. Split phase multi-channel protocol

the energy efficiency. Since the control channel is shared by all nodes for the RTS/CTS exchange, most likely, it will became bottleneck for the system performance. It goes without saying that there exists an optimal bandwidth allocation between the control channel and the data channels if the system's overall bandwidth is fixed. Because of the system's complexity, we can not get a closed form solution for the optimal bandwidth allocation. However, through numerical method, we can estimate the optimal solution by the system's upper bound and lower bound.

C. Split phase multi-channel MAC protocol

For this scheme, we assume that rough synchronization exists among nodes, which can be easily achieved by current synchronization protocols for long delay underwater networks.

As shown in Fig. 3, time is divided into multiple beacon periods. And every beacon period is divided into alternate control and data phases with duration T_c and T_d respectively. During the control phase, every node will randomly choose one channel from the available channel set for data receiving and broadcast one control message to inform other nodes of their decisions. It is possible that multiple nodes select the same receiving channel, which might lead to collisions. To make every node in the network has certain probability to get channels for transmission. the control phase should be long enough to guarantee every node's control packets to be heard by others with certain probability.

This scheme does not need one dedicated control channel. It splits time into control phase and data phase. Our analysis results show that the system performance is closed related to the ratio between the length of the control phase and that of the data phase. And its performance is not affected by the propagation delay.

III. Simulation Result

In our simulations, we change the average propagation delay from 0.1 second to 0.6 second. Correspondingly, the average distance between nodes varies from 150m to 900m, which covers the most typical underwater sensor networks.

Fig. 4 and Fig. 5 clearly show us the performance of the RTS/CTS degrades much with the increase of the propagation delay. While the other two cases are not affected at all by the propagation delay because of their random features. For networks with dynamic propagation delays, random Aloha scheme and split phase scheme can provide a stable performance to the upper layer applications.

IV. Conclusions

In this work, we investigate multi-channel MAC protocols for long delay underwater sensor networks. Three popular MAC protocols, Random multi-channel Aloha Access protocol, Multi-channel protocol with RTS/CTS on a dedicated

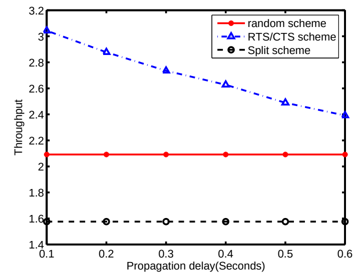

Fig. 4. Throughput with the number of the average propagation delay

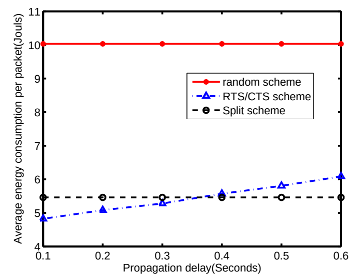

Fig. 5. Average energy consumption with the average propagation delay

control channel and Split phase multi-channel protocol are analyzed and compared. The long-delay feature of underwater acoustic channel complicates the analysis and design process. Our simulation results show that in most cases, although "Random scheme" and " Split scheme" simplify the protocol procedure, it can not provide good system performance in terms of both throughput or energy efficiency in most cases. intricate control process such as RTS/CTS like channel reservation process can augment the system performance much even in long delay underwater environments. However, "Random scheme" and "Split scheme" can achieve stable performance even with different propagation delays, And thus, they are more suitable for dynamic network conditions .

References

[1] M. Molins and M. Stojanovic, "Slotted FAMA: A MAC protocol for underwater acoustic networks," in *Proceedings of the IEEE Oceans Conference*, May 2006, pp. 1–7.

[2] B. Peleato and M. Stojanovic, "Distance aware collision avoidance protocol for ad-hoc underwater acoustic sensor networks," *IEEE Communication Letters*, vol. 11, no. 12, pp. 1025–1027, December 2007.

[3] V. Rodoplu and M. K. Park, "An energy-efficient MAC protocol for underwater wireless acoustic networks," in *Proceedings of the IEEE Oceans Conference*, May 2005, pp. 1198–1203.

[4] J. Mo, H.-S. Wilson, and J. Walrand, "Comparison of multichannel mac protocols," *IEEE Transaction on Mobile Computing*, vol. 7, no. 1, pp. 50–65, January 2008.

[5] Y. S. Han, J. Deng, and Z. J. Haas, "Analyzing multi-channel medium access control schemes with ALOHA reservation," *IEEE Transaction on Wireless Communications*, vol. 5, no. 8, pp. 2143–2152, August 2006.

[6] H.-X. Tan and W. K. G. Seah, "Distributed cdma-based mac protocol for underwater sensor networks," in *Proceedings of the 32th IEEE Conference on Local COmputer Networks*, 2007, pp. 26–36.

[7] D. Pompili, T. Melodia, and I. F. Akyildiz, "A distributed cdma medium access control for underwater acoustic sensor networks," in *Proceedings of Mediterranean Ad Hoc Networking Workshop*, 2007.

[8] F. Salva-Garau and M. Stojanovic, "Multi-cluster protocol for ad hoc mobile underwater acoustic networks," in *Proceedings of the IEEE Oceans Conference*, 2003, pp. 91–98.