UMMAC: A Multi-Channel MAC Protocol for Underwater Acoustic Networks

Yishan Su and Zhigang Jin

Abstract: **In this paper, we propose a multi-channel medium access control (MAC) protocol, named underwater multi-channel MAC protocol (UMMAC), for underwater acoustic networks (UANs). UMMAC is a split phase and reservation based multi-channel MAC protocol which enables hosts to utilize multiple channels via a channel allocation and power control algorithm (CAPC). In UMMAC, channel information of neighboring nodes is gathered via exchange of control packets. With such information, UMMAC allows for as many parallel transmissions as possible while avoiding using extra time slot for channel negotiation. By running CAPC algorithm, which aims at maximizing the network's capacity, users can allocate their transmission power and channels in a distributed way. The advantages of the proposed protocol are threefold: 1) Only one transceiver is needed for each node; 2) based on CAPC, hosts are coordinated to negotiate the channels and control power in a distributed way; 3) comparing with existing RTS/CTS MAC protocols, UMMAC do not introduce new overhead for channel negotiation. Simulation results show that UMMAC outperforms Slotted floor acquisition multiple access (FAMA) and multi-channel MAC (MMAC) in terms of network goodput (50% and 17% respectively in a certain scenario). Furthermore, UMMAC can lower the end-to-end delay and achieves a lower energy consumption compared to Slotted FAMA and MMAC.**

Index Terms: **Medium access control (MAC) protocol, multi-channel, underwater acoustic networks (UANs).**

I. INTRODUCTION

SINCE acoustic communication has been proved to be a practical method for long range wireless communication in underwater, underwater acoustic networks (UANs) have gained tremendous attention in the past decade. UANs enable wide range applications such as disaster prediction, commercial/scientific exploration. All the applications motivate a development of efficient and reliable UANs [1]–[4].

However, there is a grand challenge for the advance of UANs: Limited bandwidth. Current acoustic communication system is up to 40 km$\times$kbps for the range-rate product [5]. The limited bandwidth highly degrades network performance and makes medium access control (MAC) protocol design a daunting challenge. Many MAC protocols dedicated to UANs have been proposed in recent years to improve the network performance such as cluster-based on-demand time sharing MAC solution (COD-TS) [6], T-Lohi [7], and Slotted floor acquisition multiple access (FAMA) [8].

Nevertheless, most of the existing MAC protocols for UANs tend to improve the network performance especially the throughput/goodput by carefully scheduling the packet transmission to avoid possible collisions. Most of these protocols only consider a single channel scenario. However, considering the long propagation delay of acoustic signal in underwater, traditional request-to-send/clear-to-send (RTS/CTS) based MAC protocols may lead to an inefficient data exchange. For example, in Slotted FAMA [8], we need four slots to finish a data packet's exchange which may takes tens of seconds even we only transmit a short data packet. However, the data packet itself only consumes a small portion of the four time slots. This means that even with a lower data rate/bandwidth, the time period it takes to finish one data packet exchange might remain the same. This motivates us to better utilize the channel resource by dividing the total available bandwidth into several sub-channels. The corresponding MAC scheme is called multi-channel MAC protocol. With the availability of multi-channel underwater acoustic modems, multi-channel protocols for UANs have become possible and promising [9]. Besides, numerous works on wireless sensor networks (WSNs) have shown that multi-channel scheme can highly improve the network performance including higher throughput and lower end-to-end delay by exploring as many parallel transmissions over different frequency channels as possible in the network [10], [11].

In this paper, we investigate the use of multi-channel MAC protocol to improve the performance of UANs regarding goodput, end-to-end delay and energy consumption of the network. Comparing with many existing multi-channel MAC protocols dedicated to WSNs, our proposed multi-channel MAC protocol, named underwater multi-channel MAC protocol (UMMAC), takes advantage of the long propagation delay of acoustic signals to collect channel information which is defined as the channel gain between senders and receivers. With the channel information, a UAN node can negotiate with its neighbors and be assigned a channel for data transmission distributedly. UMMAC is a split phase multi-channel MAC protocol which requires only one transceiver. The most challenge for a split phase multi-channel protocol is to find an efficient method of channel negotiation. To solve this problem, we propose a channel allocation and power control algorithm (CAPC). CAPC allocates the channel and power level for data transmission with the aim of maximizing the network throughput. With CAPC, UMMAC allows for as many parallel transmissions as possible without an extra negotiation slot. Additionally, to reduce the overhead resulted from control packets, a packet train scheme is adopted.

Manuscript received July 6, 2014; approved for publication by Homayoun Yousefi'zadeh, Division II Editor, February 10, 2015.

This work has been supported by the National Natural Science Foundation of China through the Grants 61571318 and Qinghai Science and Technology Project No. 2015-ZJ-904.

The authors are with the Department of Communication and Information Engineering, Tianjin University, China, email: suyishan_tj@hotmail.com, zgjin@tju.edu.cn.

Digital object identifier 10.1109/JCN.2016.000010