Applying frame aggregation and block acknowledgement to increase channel utilization in UASNs

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***Abstract*—Underwater acoustic sensor networks (UASN) significantly differ from the terrestrial wireless sensor networks (WSNs) due to the nature of acoustic channels in underwater environments. In contrast to the radio channels, acoustic channels suffer from lower propagation delay and limited bandwidth. Under such conditions, medium access layer (MAC) overheads affect badly to the performance of UASNs. In this paper, we are exploiting some of the features of IEEE 802.11n for minimizing the MAC layer overheads in acoustic medium based communication and for improving the channel utilization. We apply A-MPDU frame aggregation and block acknowledgement (BA) functionalities to the acoustic channels to improve the performance of MAC layer. Our evaluations show that the application of these features to the MAC layer helps to reduces the MAC overheads improving the network throughput significantly.**

I. Introduction

Underwater acoustic sensor networks (UASN) are composed of networked devices which are submerged in the ocean or some other water reservoir for various applications ranging from civil purposes such as undersea oil pipeline monitoring to military purposes such as intruder detection [1]. In contrast to terrestrial wireless sensor networks, UASNs cannot deplend on radio magnetic waves for communication among the nodes due to its poor propagation and high attenuation in the water [2], [3]. Therefore UASNs use acoustic signals for communication which however introduces many new challenges. Acoustic signals propagate through the water in a speed of $1500m/s$ which is a five orders of magnitude lower than the propagation speed of radio signals in terrestrial environments. Additionally limited bandwidth in acoustic signals makes the UASN devices challenged in communicating to each other. With such an environment, UASN devices have to make best use of the available capabilities of communication medium.

Medium access layer (MAC) overheads are affecting badly to the performance of UASN in many ways. Each frame sent from a node consists of MAC headers. After a frame is sent from a node to a neighbor, the sender has to keep an inter-frame space before another transmission of a frame which again consists of MAC headers. Additionally the sender has to wait a significant time period for acknowledgements of previous transmission. When channel is busy, a sender has to back-off for a random time period before attempting to transmit a frame again. Due to the low propagation speed and limited bandwidth in acoustic signals, this behavior of MAC layer wastes the network resource reducing the throughput while increasing the delay.

In this paper we exploits some of the features of IEEE 802.11n specification [4] to address those MAC layer overheads in underwater acoustic sensor networks. Using simulation based evaluations, we show that frame aggregation and block acknowledgement as defined in IEEE 802.11n can increase the performance of acoustic channels leading to higher network throughput and lower delays. The rest of the paper is organized as follows. In Section II we describe some of the related work. Section III introduces our frame aggregation and block acknowledgement scheme based on IEEE 802.11n while Section IV evaluates its performance improvements. Finally Section V concludes the paper.

II. Related Work

Many schemes have been proposed to address the MAC layer overheads in terrestrial wireless sensor networks even though this area is less explored for acoustic channels in UASNs. In [5], the authors presents DACAP; a MAC scheme for UASNs which avoids collisions in the acoustic channels by utilizing a warning frame in addition to the RTS/CTS frames. Even though it improves the network throughout comparing to ALOHA, still their scheme suffers from MAC layer specific overheads described in the previous section. A comprehensive performance evaluation between CSMA and DACAP is presented in [6] which concludes that size of the packets/frames transmitted in acoustic channels has a significant effect on the performance of the network in terms of throughput and end-to-end delay.

The authors of [7] have considered the application of IEEE 802.11 MAC on underwater acoustic communication. While the IEEE 802.11 is suffering from MAC layer overheads in the terrestrial environments, the impact in the underwater acoustic channels are worse due to the lower propagation speed and bandwidth. The introduction of IEEE 802.11n [4] in terrestrial environments has proved to improve the channel utilization by using various mechanisms including frame aggregation techniques [8].

III. Frame Aggregation For UASNs

In terrestrial environments, IEEE 802.11 wireless networks are facing many similar challenges which are faced in underwater acoustic networks. Size of frame headers, inter-frame space, back-off timers and acknowledgements at the MAC layer is wasting the limited network bandwidth. Due to these issues, a novel specification was introduced named as IEEE 802.11n which takes several actions to address the MAC layer limitations in IEEE 802.11 specification. Among different other enhancements, we consider frame aggregation at the MAC layer defined in IEEE 802.11n which significantly reduces the overhead exist in terrestrial wireless networks.

Frame aggregation functionality of IEEE 802.11n can be performed in two ways namely (a) aggregation of MAC service data units and (b) aggregation of MAC protocol data units. In the former method, aggregation is performed by collecting multiple MAC service data units (MSDUs) which are received from the networking layer and creating a larger single aggregated MAC service data unit called A-MSDU. When producing the output of the MAC layer by adding the MAC layer specific headers, this A-MSDU is used and therefore many MAC layer overheads are reduced. In the latter method, multiple MAC protocol data units (MPDUs) which contains MAC layer specific headers are aggregated to form a large single aggregated MAC protocol data unit called A-MPDU. When MAC layer is handing over a frame to the physical layer, these large A-MPDUs are used reducing the overheads of the MAC layer. Even though such two approaches are suggested in the IEEE 802.11n specification, the implementation of either A-MSDU or A-MPDU is a choice of the developer. When A-MPDU is used, there should be a block acknowledgement (BA) mechanism since a single physical layer frame will contain a collection of aggregated MAC protocol data units (MPDUs) which require individual acknowledgements.

To improve the performance of UASNs which use acoustic channels, we are applying the same frame aggregation feature of IEEE 802.11n which reduces the MAC layer overheads significantly. From the two methods defined in specification, in this paper, we are specifically applying the A-MPDU frame aggregation together with block acknowledgement (BA) to UASNs. In our UASN scenarios, we identified that the original frame formats and functionalities defined in the IEEE 802.11n specification can be directly applicable for underwater acoustic channels. In the following, we are explaining how the A-MPDU frame aggregation with block acknowledgement is performed for acoustic channels.

Figure 1 shows the attributes of A-MPDU frame structure which is composed of MPDU subframes. The goal of A-MPDU is to transmit multiple MPDU subframes with a single physical layer header by which the overhead of sending multiple separate MAC frames is reduced. Each MPDU subframe consists of a header which is called MPDU delimiter and a footer which consists of some padding bytes. The MPDU delimiter is 32 bits long and the initial 4 bits of it are reserved. The rest of the MPDU delimiter is consists of a 12 bits long MPDU length field, a 8 bits long CRC field and a 8 bits long signature field. The padding bytes of an MPDU frame can vary between 0 to 3 bytes for the purpose of rounding the MPDU frame to the word boundary of 32 bits. Multiple such MPDU subframes are aggregated to form a single large A-MPDU and in a single A-MPDU, all the MPDU subframes should be addressed to the same destination. However these MPDU subframes can contain different source addresses. This large A-MPDU is handed over to the physical layer as a single

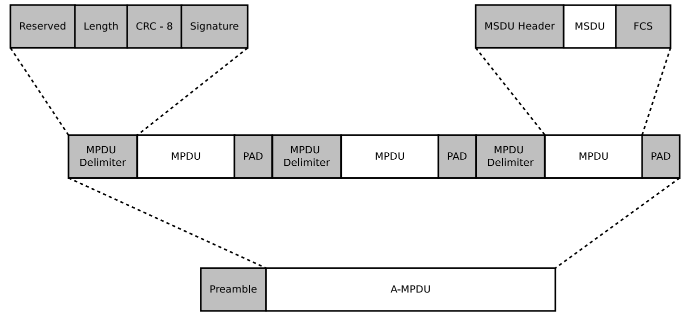

Fig. 1. The composition of A-MPDU aggregated frames as defined in IEEE 802.11n specification. Each individual MAC service data unit (MSDU) is enclosed between a MSDU header and FCS bytes to make them MPDU frames. These MPDU frames are aggregated together to buildl A-MPDU frames. Such an A-MPDU is consists of MPDU subframes together with their MPDU delimiters and paddings.

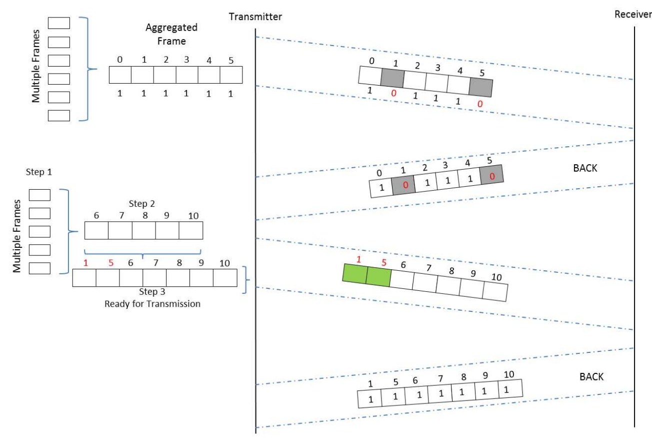

Fig. 2. Block Acknowledgement mechanism of IEEE 802.11n where multiple aggregated frames from a sender are acknowledged by a single acknowledgement frame saving the network resources.

unit which will be transmitted from the physical layer as a single unit which is called physical layer protocol data unit (PPDU) together with physical layer specific preambles.

When multiple frames are sent from a source to a receiver in an aggregated form, acknowledging each frame separately is a costly task. A sender has to wait for acknowledgements of the transmitted frames before performing next transmission. Therefore a block acknowledgement (BA) mechanism can improve the performance of the network where multiple frames are acknowledged by a single acknowledgement message. We adopted the block acknowledgement mechanism of IEEE 802.11n shown in Figure 2 for the underwater acoustic channels in UASNs.

IV. Performance Evaluations

On evaluating our MAC scheme which contains A-MPDU frame aggregation and block acknowledgement (BA) features of IEEE 802.11n, we compared it against a representative MAC scheme which follows the specification of IEEE 802.11 in the underwater conditions. We focused on the throughput variation of both schemes with the increasing number of network sizes. Network throughput is calculated by dividing the total number of packets transferred from the simulation

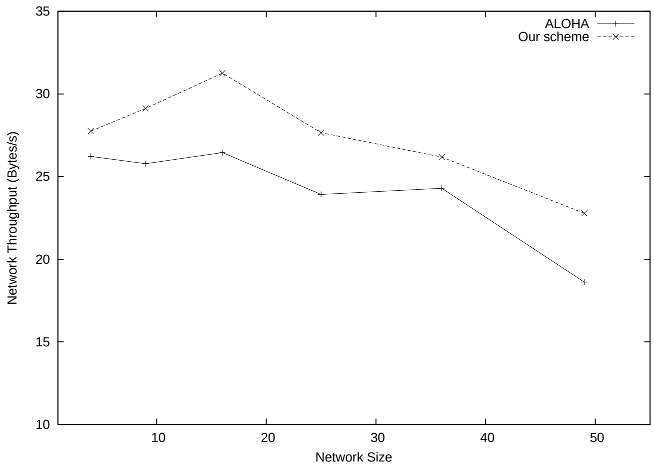

Fig. 3. Throughput variation over different network sizes.

time.

We performed evaluations of the two schemes based on the above simulation metric on Aqua-Sim simulator [9]. In the simulations, a 3-dimensional underwater territory of $100Km \times 100Km \times 100Km$ is considered where variable number of nodes are deployed randomly. Half of the nodes are sender nodes which are sending packets over a single hop to their neighboring node. Physical layer of each node is configured to simulate $914MHz$ Lucent WaveLAN DSSS radio interface to achieve better realistic behavior.

Figure 3 shows the variation of network throughput with the variable number of nodes in the two schemes. It is evident that our scheme achieves a higher throughput compared to the traditional 802.11 based medium access scheme. Since multiple frames are aggregated as a single unit before transmitting from the channel, our scheme can deliver more data frames in a single medium access. In contrast, traditional ALOHA based scheme has to go through a time consuming process to access the channel several times to deliver the same amount of bytes delivered in a single channel access by our scheme. This phenomenon results in a higher throughput in our scheme as the Figure 3 depicts.

V. Conclusion

In this paper, we exploited the A-MPDU frame aggregation and block acknowledgement (BA) features defined in IEEE 802.11n specification to the the underwater acoustic channels. Due to the nature of acoustic channels, UASNs are suffering from limited bandwidth and low propagation delays. Therefore its necessary to minimize the overheads of MAC layer to increase the utilization of acoustic channels. In our evaluations on the ns2 simulator, we have shown that the application of frame aggregation and block acknowledgement contributes to increase network throughput in communication over acoustic channels. As future work, we are working on to evaluate A-MSDU frame aggregations in addition to A-MPDU frame aggregation in acoustic channels to investigate the ways to improve acoustic channel utilization by minimizing MAC layer overheads.

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