Reservation Protocol Delay in Maritime Systems

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***Abstract*—The paper considers the delay of a maritime system that consists of a sea-to-shore radio communication channel and an underwater acoustic random access network. First, the delay of the reservation protocol operating over the radio communication channel is evaluated by itself. Next, the overall delay for the reservation protocol operating over the radio communication channel and the underwater acoustic random access network based on the stabilized CSMA slotted Aloha protocol is evaluated as well. Numerical examples are presented that illustrate the delay performance.**

I. Introduction

The importance of effective sea-to-shore transmission of information has inspired research and development of maritime systems [1]. This has been necessitated by the need for ocean monitoring [2] and coastal ocean observation [3] including reliable collection and transfer of data [4], [5].

We consider a scenario where an underwater acoustic network communicates with a surface buoy station. Let the underwater acoustic network be a random access network where bottom mounted sensor nodes collect data and transmit it to an aggregation point, say, a surface buoy station. The random access protocol is based on the stabilized carrier sense multiple access (CSMA) slotted Aloha protocol [6]. It is assumed that the packets generated by the bottom mounted sensor nodes can be described by independent Poisson processes. A property of the pseudo-Bayesian stabilized CSMA slotted Aloha protocol is that the number of packets for transmission remains Poisson distributed given an idle slot or a successful packet transmission, or is well approximated as Poisson distributed given a packet collision [7]. It is therefore assumed that the packet arrival process at the surface buoy station is also Poisson distributed. In the considered data collection scenario, the surface bouy station uses radio communication to transmit the gathered data to an on shore data center [8]. It is assumed that the communication between the surface bouy station and the on shore data center is based on the reservation protocol. As the name suggests, the reservation protocol is characterized by the fact that there are reserved intervals for channel use.

The aim of the paper is to analyze the delay from a queueing theory perspective [7]. The delay of the reservation protocol itself is considered first. This is then followed by an evaluation of the overall maritime system delay. The overall delay consists of the delay of the stabilized CSMA slotted Aloha protocol operating over the underwater acoustic channel [6] and the delay of the reservation protocol operating over the radio transmission channel.

The paper is organized as follows. Section II overviews the reservation protocol. It highlights the queueing delay for several versions of the reservation protocol including the exhaustive, the partially gated, and the gated systems. Section III analyzes the delay performance of the reservation protocol operating over the radio transmission channel between the surface buoy station and the on shore data center. Section IV presents numerical examples that illustrate the delay performance for the reservation protocol itself, as well as the overall delay for the stabilized CSMA slotted Aloha protocol and the reservation protocol. Section V concludes the paper.

II. Reservation Protocol

The reservation protocol differentiates the communication of information across time between data intervals, used for the transmission of information, and reservation intervals, used for scheduling future data transmissions [7]. In principle, there could be, say, m stations, whose transmissions are scheduled in a cyclic fashion. It is assumed that each station has independent Poisson arrivals of rate λ/m. The first two moments of the service times for each station's packets are $\overline{X}$ and $\overline{X^2}$, respectively. The duration of the reservation interval for an entire cycle of reservations across all stations is denoted by τ. The reservation protocol is characterized by the manner in which packets are transmitted during each station's data interval.

In an exhaustive system, all packets are transmitted, including packets that arrive during the station's data interval. The waiting time for an exhaustive system is [7]

$$W = \frac{\lambda \overline{X^2}}{2(1-\rho)} + \frac{\tau}{2}\left(\frac{1-\frac{\rho}{m}}{1-\rho}\right). \quad (1)$$

In a partially gated system, only packets that are transmitted are those which have arrived prior to the start of that data interval. The waiting time for a partially gated system is [7]

$$W = \frac{\lambda \overline{X^2}}{2(1-\rho)} + \frac{\tau}{2}\left(\frac{1+\frac{\rho}{m}}{1-\rho}\right). \quad (2)$$

In a gated system, only packets that are transmitted are those which have arrived prior to the station's previous reservation interval. The waiting time for a gated system is [7]

$$W = \frac{\lambda \overline{X^2}}{2(1-\rho)} + \frac{\tau}{2}\left(\frac{1+\frac{2-\rho}{m}}{1-\rho}\right). \quad (3)$$

III. Reservation Protocol Delay Analysis

We evaluate the sea-to-shore delay in the context of the reservation protocol. This is an appealing solution since the channel can be suitably reserved based on the dynamic transmission requirements. The surface buoy station transmits packets to the on shore data center over the radio communication channel. Note that the propagation time over the radio communication channel is neglected. We consider deterministic service. The packet duration is normalized to unity. Therefore, $\overline{X} = 1$ and $\overline{X^2} = 1$. For simplicity, the duration of the reservation interval is also taken to be $\tau = 1$. We assume Poisson packet arrivals at rate λ. The utilization factor is $\rho = \lambda\overline{X} = \lambda$. We let $m = 1$. We evaluate the queueing delay for the exhaustive, the partially gated, and the gated versions of the reservation protocol.

The waiting time for the exhaustive system is [7]

$$W = \frac{\lambda}{2(1-\lambda)} + \frac{1}{2} = \frac{1}{2(1-\lambda)}. \tag{4}$$

The waiting time for the partially gated system is [7]

$$W = \frac{\lambda}{2(1-\lambda)} + \frac{1+\lambda}{2(1-\lambda)} = \frac{1+2\lambda}{2(1-\lambda)}. \tag{5}$$

The waiting time for the gated system is [7]

$$W = \frac{\lambda}{2(1-\lambda)} + \frac{3-\lambda}{2(1-\lambda)} = \frac{3}{2(1-\lambda)}. \tag{6}$$

The system delay follows as

$$T = W + 1. \tag{7}$$

IV. Numerical Results

The delay performance of the maritime system is illustrated by numerical examples. First, we illustrate the delay performance for the reservation protocol operating over the radio communication channel between the surface buoy station and the on shore data center. The propagation time over the radio communication channel is neglected. The packet arrival rate is $0 \leq \lambda \leq 1$.

Figure 1 illustrates the delay performance of the exhaustive reservation protocol. It can be observed that for the most part the delay is around 3 s.

Figure 2 illustrates the delay performance of the partially gated reservation protocol. It can be observed that for the most part the delay is around 9 s.

Figure 3 illustrates the delay performance of the gated reservation protocol. It can be observed that for the most part the delay is around 11 s.

Next, we illustrate the overall delay performance for the reservation protocol operating over the radio communication channel and the stabilized CSMA slotted Aloha protocol operating over the underwater acoustic channel. The roundtrip distance between the bottom mounted sensor nodes on the perimeter of the monitored area and the aggregation point, surface buoy station, is taken to be $d = 300$ m [6]. Note that the speed of sound propagation underwater is $c = 1500$ m/s [9].

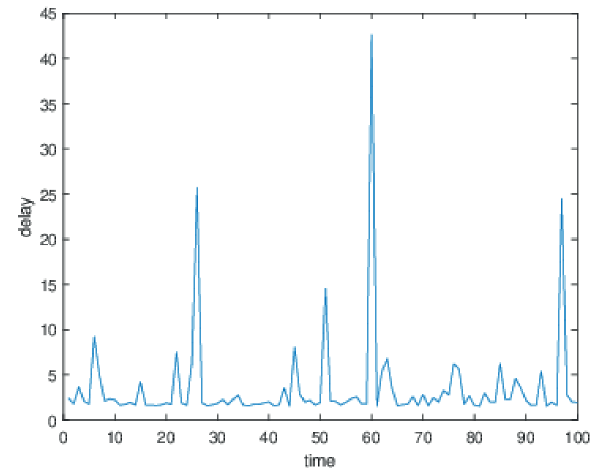

Fig. 1. Delay performance of the exhaustive reservation protocol.

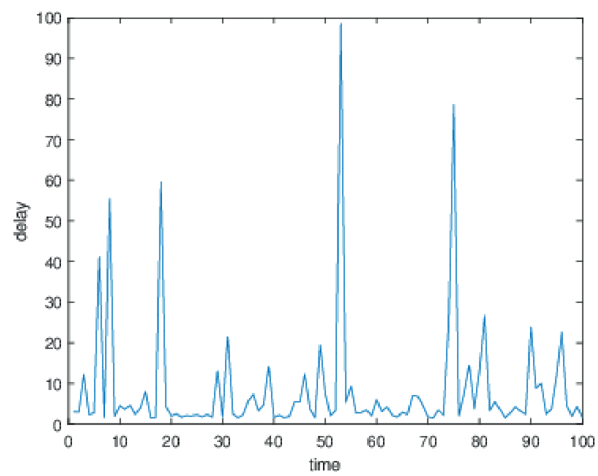

Fig. 2. Delay performance of the partially gated reservation protocol.

Figure 4 illustrates the overall delay for the CSMA slotted Aloha network with $d = 300$ m and the exhaustive reservation protocol. It can be observed that for the most part the overall delay is around 6 s.

Figure 5 illustrates the overall delay for the CSMA slotted Aloha network with $d = 300$ m and the partially gated reservation protocol. It can be observed that for the most part the overall delay is around 12 s.

Figure 6 illustrates the overall delay for the CSMA slotted Aloha network with $d = 300$ m and the gated reservation protocol. It can be observed that for the most part the overall delay is around 14 s.

It can be observed that the best delay performance is obtained by the exhaustive version of the reservation protocol. This is because in the exhaustive version of the reservation protocol all available packets are transmitted during the data interval. This includes queued packets, as well as packets that arrive during the data interval itself.

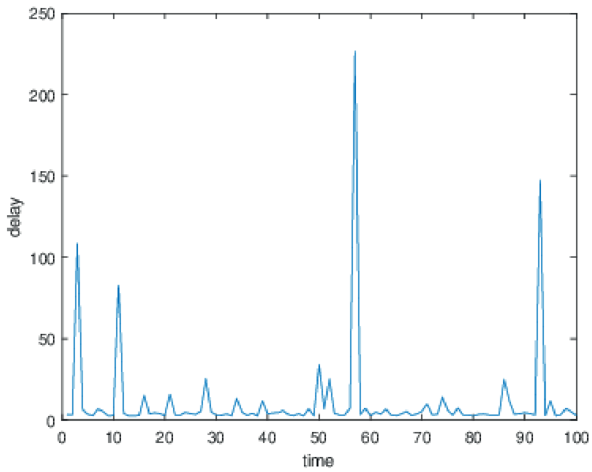

Fig. 3. Delay performance of the gated reservation protocol.

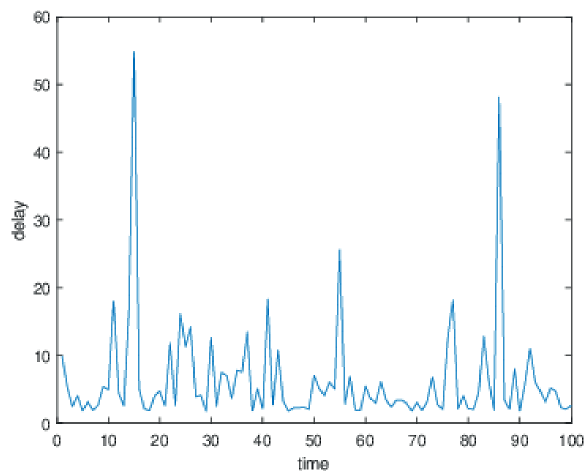

Fig. 4. An overall delay performance of the exhaustive reservation protocol and the CSMA slotted Aloha network with $d = 300$ m.

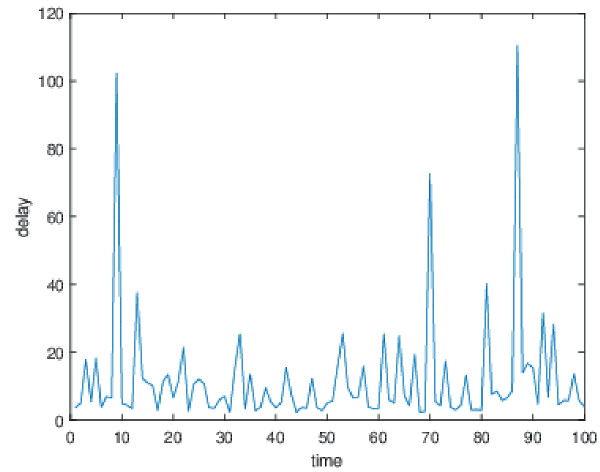

Fig. 5. An overall delay performance of the partially gated reservation protocol and the CSMA slotted Aloha network with $d = 300$ m.

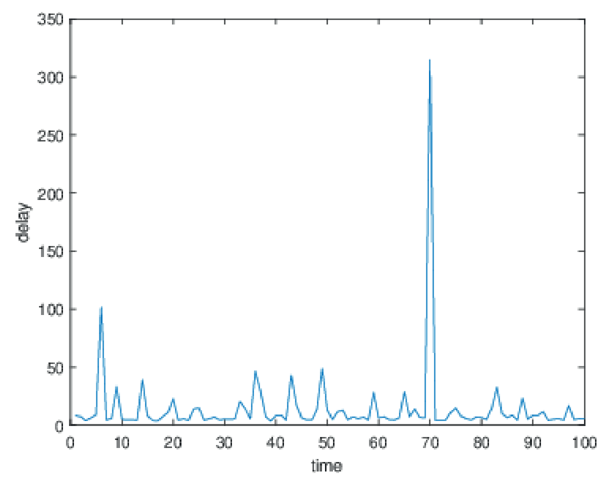

Fig. 6. An overall delay performance of the gated reservation protocol and the CSMA slotted Aloha network with $d = 300$ m.

V. Conclusions

The paper considered the delay performance of a maritime system that consisted of a sea-to-shore radio communication channel and an underwater acoustic random access network. The sea-to-shore radio communication channel was between a surface buoy station and an on shore data center. The radio communication channel utilized the reservation protocol. The underwater acoustic random access network was between bottom mounted sensor nodes and the surface buoy station. The underwater acoustic random access network utilized the stabilized CSMA slotted Aloha protocol. The delay of the reservation protocol operating over the radio communication channel was evaluated first. The overall delay for the stabilized CSMA slotted Aloha protocol operating over the underwater acoustic channel and the reservation protocol operating over the radio communication channel was evaluated next. The delay performance was illustrated by numerical examples.

References

[1] G. Reddy, "Maritime Domain Awareness," The Journal of Ocean Technology, vol. 10, no. 2, pp. 1–103, 2015.

[2] L. Bellavance, "Ocean Monitoring," The Journal of Ocean Technology, vol. 8, no. 3, pp. 1–85, 2013.

[3] B. Carter, "Coastal Ocean Observation," The Journal of Ocean Technology, vol. 13, no. 1, pp. 1–150, 2013.

[4] S. Jiang, "On Reliable Data Transfer in Underwater Acoustic Networks: A Survey From Networking Perspective," IEEE Communications Surveys & Tutorials, vol. 20, no. 2, pp. 1036–1054, 2018.

[5] X. Wei, H. Guo, X. Wang, X. Wang and M. Qiu, "Reliable Data Collection Techniques in Underwater Wireless Sensor Networks: A Survey," IEEE Communications Surveys & Tutorials, vol. 24, no. 1, pp. 404–431, Dec. 2021.

[6] A. Stefanov, "Delay in Underwater Acoustic CSMA Networks," Proceedings of the 6th International Conference on Artificial Intelligence in Information and Communication, Osaka, Japan, Feb. 2024.

[7] D. Bertsekas and R. Gallager, "Data Networks," Prentice Hall, 1992.

[8] B. Randell, "Data Pickers of the Ocean," The Journal of Ocean Technology, vol. 18, no. 3, pp. 1–124, 2023.

[9] L. Brekhovskikh and Y. Lysanov, "Fundamentals of Ocean Acoustics," Springer, 1982.