"Busy Terminal Problem" and Implications in Underwater Acoustic Networks

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1. INTRODUCTION

Underwater acoustic networks have become a very active research area during the past half decade. Compared with terrestrial radio networks, underwater acoustic networks are characterized by low available bandwidth, long propagation delays and high channel dynamics, which pose significant challenges to the design and analysis of almost every core networking problem [1], including medium access control (MAC), routing, and reliable data transfer. In this paper, we study a previously overlooked problem named the busy terminal problem, which is significantly impacts underwater MAC.

2. BUSY TERMINAL PROBLEM

In underwater networks, it has been noticed that underwater acoustic modems work in a half-duplex way. Most existing underwater MAC protocols follows the restrictions posed by the half-duplexity, i.e., an acoustic modem cannot send and receive simultaneously, but they assume that a modem can interrupt the sending and receiving states at will to send another packet. For example, as illustrated in Fig. 1(a), during the reception of the packet from A, node B can interrupt the packet reception at time t and switch to transmit its own packet to C. In fact, this is how existing MAC protocols handle the exposed terminal problem to improve the channel utilization [3]. However, according

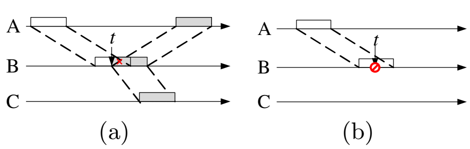

Figure 1: (a) Half duplexity; (b) Busy terminal problem

to a recent observation, all existing acoustic modems, like Benthos Modem [4], cannot be interrupted when receiving or sending a packet. In other words, an underwater node cannot switch between the sending and receiving states at will to transmit another packet. This is determined by the acoustic modem design.

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For example, referring to Fig. 1(b), node A is transmitting a data packet and B can overhear it. Even if the packet is not for B, B cannot send during the reception of the packet from A. In addition, A cannot interrupt the current packet transmission for another packet. As we can see, the essential problem in both situations is that a modem cannot be interrupted when it is sending or receiving, and the modem appears to be too "busy" to send newly arrived packets.

Definition 1. In underwater acoustic networks, a node cannot interrupt the current packet reception/transmission to send another packet. We call this phenomenon the **busy terminal problem (BTP)**.

Note that **BTP differs from half duplexity**. Half duplexity only prohibits a modem from sending and receiving simultaneously, but a modem can still interrupt the current packet reception/transmission. However, when the BTP arises, the modem is no longer able to interrupt the packet reception/transmission processes. To summarize, in addition to the constraints posed by half duplexity, the BTP does not allow a node to interrupt the packet reception/transmission procedures. The root causes of the BTP are the *non-interruptability* and half duplexity of acoustic modems.

3. IMPACT OF BTP ON MAC PROTOCOLS

BTP only impacts the performance of un-slotted MAC protocols. In slotted approaches, a packet can only be sent at the beginning of the slot and received by neighbors before the end of the same slot. Therefore, a node must not be in the receiving state when it is trying to send out a packet. That is, a node is able to send out packets at will and will not be affected by the BTP.

In existing un-slotted MAC protocols, BTP has not been considered. Instead, it is commonly assumed that a node can interrupt the current packet reception and switch to sending. However, this assumption does not hold because of the BTP. Due to the BTP, packets cannot be sent out as needed. Thus, the packet sending pattern is changed, which further affects protocol performance.

Specifically, in random access MAC protocols nodes cannot randomly access the channel by sending out packets at will. Thus, the BTP helps to reduce the rate that packets are actually sent to the channel and results in a lower collision probability. In other words, *BTP may benefit random access MAC protocols.*

As for reservation/scheduling based MAC protocols, BTP may cause disruptions. In order to improve the channel utilization, protocols like [3] handle the exposed terminal problem by scheduling the transmissions in advance. Because of the BTP, however, a node may not be able to send a packet at the pre-scheduled time point, which further disturbs the schedule and may cause collisions. Therefore, *BTP may impair the performance of reservation/scheduling based MAC protocols.*

4. HOW TO HANDLE BTP?

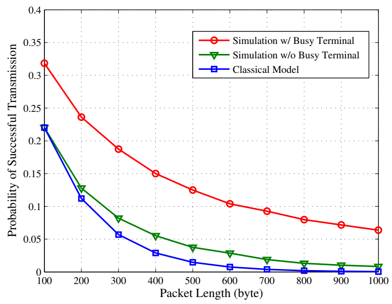

Figure 2: Gap between the classic model and simulation

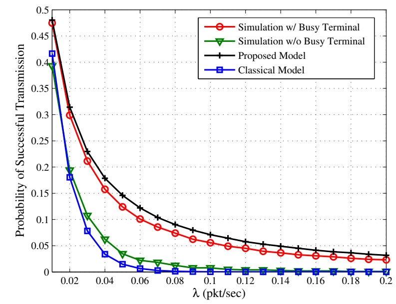

Figure 3: Model validation with varying packet generation rate

As discussed above, BTP does not affect slotted MAC protocols, so we only discuss the solution for un-slotted approaches. In random access MAC protocols, nodes do not know when a packet will arrive, so it is impossible for a random access MAC protocol to avoid the BTP. For reservation/scheduling based MAC protocols, the BTP can be handled by ensuring that a packet is transmitted only when the modem is idle in addition to guaranteeing the conventional requirements for collision avoidance. However, this solution only works for the packets whose sending time can be pre-scheduled. The sending pattern of control packets are still affected by the BTP because they are sent to the channel following a random access (i.e., ALOHA-like) approach.

5. IMPACT OF BTP ON RANDOM ACCESS BASED MAC

From the discussion above, we can see that there is no valid solution for packets sent in a random access manner, so it is desirable to understand how the BTP affects random access approaches. Because ALOHA is one of the basic MAC protocols and has been referred by many other advanced MAC protocols, where the control packets are transmitted using the random access (i.e., ALOHA-like) approach, it is necessary to study the impact of BTP on ALOHA as the first step.

To study the impact, we conducted simulations to evaluate the performance of ALOHA with and without consideration of BTP. Meanwhile, we compared the classic collision model of ALOHA [2] with the simulation results to check its accuracy. The simulation settings are identical to those in Section 6, the simulation results section, and we do not repeat them here due to space limitations. Setting Poisson traffic rate λ to $0.1pkt/s$ and varying packet size from $100B$ to $1000B$ produces the results in Fig. 2.

From Fig. 2, we can see that the classic model closely matches the simulation results when the BTP is ignored. This confirms that the classic model still works in underwater acoustic networks although the propagation delays are undesirable. When the BTP is considered, however, in Fig. 2 it is also observed that there is a large gap between the evaluation results of the classic model and the simulation results considering the BTP. Because BTP is the only difference between these two sets of simulations, BTP must be the root reason causing the gap between the classic model and the simulations considering the BTP. Furthermore, the trends of these two curves are significantly different, so the classic model cannot accurately characterize the collision probability when BTP is considered. In order to understand the impact of BTP on packet collisions, we are developing an accurate collision model of ALOHA considering BTP. This will help guide the future MAC design and analysis for underwater acoustic networks.

6. PRELIMINARY RESULTS

We developed an analytical model of collision probability for ALOHA considering the BTP. In this section, we present the preliminary results of model verification. The simulation settings are as follows: there are 125 nodes uniformly distributed in a cube with edge E=$5000m$. The maximum node transmission range is $1100m$. Nodes generate packets of length $500B$ following an independent identical Poisson process with rate parameter λ. We refer to Benthos modem to set the modem transmission rate and preamble, i.e., the effective transmission rate is $667bps$ in the horizontal channel and the packet preamble is about $1.5s$. The bit error rate is 10^{-5}.

Varying λ from 0.01 to 0.2 in step $0.01pkt/s$ produces the simulation results in Fig. 3. In this figure, the proposed model coincides well with the simulation results considering BTP while the classic model still matches the simulation results when BTP is ignored. Because BTP is the only difference between these two sets of simulations, the comparison in Fig. 3 confirms that the proposed model can capture the impact of BTP on packet collision. It is also observed that BTP can help alleviate the collisions, especially when traffic is heavy. This occurs because nodes cannot send out packets as fast as they are generated due to BTP. That is the BTP reduces the effective rate that a node sends packets to the channel, and thus alleviates collisions in ALOHA.

7. CONCLUSION

This paper formally defines a newly identified issue in underwater acoustic networks named busy terminal problem. We have also discussed its impact on MAC protocols. To study its impact, we have further proposed a new analytical model for the successful packet transmission probability of ALOHA. Simulations confirm that accurately captures the impact of the BTP.

8. REFERENCES

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