A New MAC Based on RTT Prediction for Underwater Acoustic Networks*

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ABSTRACT

Most existing medium access control (MAC) protocols in underwater acoustic networks (UANs) ignore the delay variance that affects the estimation accuracy of round trip time (RTT). We predict the RTTs using Bayesian dynamic linear model. Using the predicted RTTs, we dynamically adjust the length of time slots in MAC. Experimental results show that the predicted values can adapt quickly to the delay variance in the acoustic channel.

Keywords

Underwater acoustic networks, medium access control (MAC), RTT estimation, Bayesian dynamic linear model.

1. INTRODUCTION

In the last decades of years, the underwater acoustic networks (UANs) have been the subject of increasing interest [1, 4, 7, 8] because they support a wide range of applications.

Underwater acoustic communication faces challenges such as high bit error rate, high propagation delay and delay variance. Tests we have performed demonstrate about 0.8 ms difference between the maximum and minimum round trip time (RTT) values for two underwater modems at a distance of only 4 meters away from each other. In an actual undersea environment, the characteristics of underwater channels may increase such differences. RTT can be used to compute the retransmission time-out (RTO). However, most of the medium access control (MAC) protocols for UANs ignore the RTT fluctuations caused by the delay variance. In terrestrial networks, a number of studies have focused on RTT estimation. In [6], the authors estimated the end-to-end RTT using a machine-learning technique known as the Experts Framework. In [3], Liang and Xu designed a smooth function of RTT exponentially weighted by ARMA models. Zhang mentioned in [9] that the system may make a wrong judgment using Jacobson-Karn's algorithm [2] when applied to a highly unreliable channel; thus, he enhanced the algorithm with a dynamic factor based on the past history of the data-loss ratio. The object of this paper is to overcome RT-T fluctuations by accurately estimating RTT using Bayesian dynamic linear model and to propose a new MAC protocol based on RTT estimation.

The remainder of the paper is organized into the following sections. In Section 2 we first demonstrate the relationship between the slot length and the throughput. Then we describe how to predict the RTT value based on Bayesian forecasting and the dynamic linear model. Finally, Section 3 concludes the paper and highlights some open issues for future work.

2. A MAC BASED ON RTT PREDICTION

In this section, we first illustrate the relationship between the throughput and the slot time in the traditional handshaking time-slotted protocol, and then propose our new protocol based on the predicted RTT value using Bayesian dynamic linear model. Finally, we detail the Bayesian's algorithm and compare the estimation performance with Jacobson's algorithm via numerical results.

2.1 Analysis of Slot Length and Throughput

For MAC protocols in UANs, especially for the slotted protocols, the throughput is subject to the waiting time related to the slot length setting. We briefly show in the following analysis the impact of the slot length on the throughput from the mathematical view using slotted-FAMA [5] protocol as an example.

Let the slot length T_{slot} be the sum of RTS transmission time and the propagation time. The slot length is assumed constant in most existing slotted hand-shaking protocols. The transmission time of a data packet is denoted as T_{data}, and the total time of transmitting one packet successfully is T_{total}. During the whole transmission process, the packet decoding error probability is assumed as a.[1]

The probability that one node cannot receive the CTS response of the other node is $w{=}P_{RTT>2T_{slot}}{+}P_{RTT<2T_{slot}}{\times}a$. The first item in the equation is the probability due to the RTT fluctuations whereas the second item is the chance of not decoding CTS correctly on the condition of reception. The time denoted by T between the start of a DATA packet

[1]We assumed the same decoding error probability for the packets.

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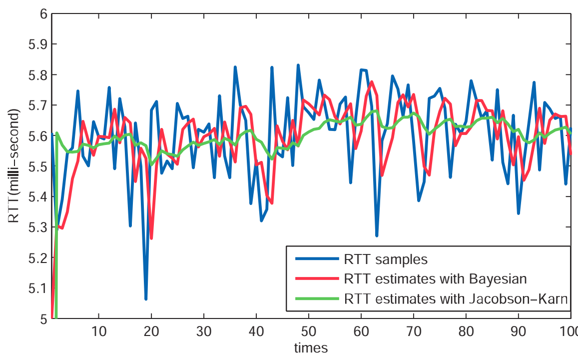

Figure 1: Sample and estimation values of RTT fluctuations.

and the time of successful reception of the ACK packet is: $T{=}\sum_{n=1}^{\infty} n(T_{data} + T_{slot}) \times (1 - (1 - a)^2)^{(n-1)} \times (1 - a)^2$.

T_1 is the time required to successfully receive the ACK in the first RTS attempt: $T_1{=}2T_{slot}{\times}(1{-}w){+}T$. As long as the RTS attempt fails, another RTS attempt is required. The total duration of a successful period includes the RTS (plus all the attempted RTSs), CTS (paired to RTS), DATA (all the retransmission due to errors), NACKs (if there's any) plus the final ACK is: $T_{total}{=}\sum_{n=1}^{\infty} n(2T_{slot}) \times w^{(n-1)} \times (1 - w) + T{=}\frac{2T_{slot}}{1-w} + T$. The throughput is equal to the reciprocal of T_{total}.

2.2 RTT Prediction-Based MAC

We propose a novel RTT prediction-based MAC by setting the slot length as follows: $T_{slot}{=}RTT_{predicted}/2{+}guardtime$. The difficulty in designing our MAC exists in the RTT prediction.

2.3 Bayesian-Based RTT Prediction

The forecasting of RTTs is of importance to the design of the MAC protocol in UANs, now we use the Bayesian's algorithm to estimate the RTT and compare it with the results from the Jacobson's algorithm.

The lab data begin at $t = 0$, so the initial experience of the RTT before receiving the first observed data is described by $m_{-1} = 5$ (millisecond), $C_{-1} = 1$ and the V and W are 4 and 3, respectively. m_{-1} is the prior value for RTT, C_{-1} is the prior variance, and V and W are the ephemeral observation variance and the sustained system variance respectively.

Therefore, the operational dynamic model for RTT in time t is :

$Y_t = \mu_t + \nu_t,\ \nu_t \sim\ N[0, 4]$,
$\mu_t = \mu_{t-1} + \omega_t,\ \omega_t \sim\ N[0, 3]$
$(\mu_0|D_0) \sim\ N[5, 1]$.

Fig. 1 depicts a plot of the one-step RTT forecasts and the observations with respect to time. We can see that the one-step forecasting values using Bayesian's algorithm respond to the observations faster even for the sudden events and follow the real measurements more closely than those using Jacobson's algorithm.

The prior information of m_{-1} is the key difference between Bayesian's algorithm and the other traditional algorithms. Although it is the subjective experience, its contribution to calculating the later one-step forecasting decays to zero as t increases.

3. CONCLUSION

We overcame the RTT fluctuations by presenting a novel approach of predicting RTTs using Bayesian forecasting with dynamic linear models because of the non-stationary characteristics of RTT series. We proposed a new MAC protocol to overcome the RTT fluctuations based on RTT prediction. We demonstrated that the estimated RTT values match the samples well even for the unexpected event. Our study highlights the value of predicting the RTT using Bayesian's algorithm in underwater acoustic networks. Based on our results, we conclude that the Bayesian's algorithm is an ideal candidate for RTT prediction in underwater acoustic networks. Our future work will investigate the following important issues: 1) implementing the forecasting algorithm into the NS2 simulator; and 2) verifying its effectiveness in underwater acoustic networks through experiment.

4. REFERENCES

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