Retransmission Efficiency Investigation in Underwater Acoustic Networks

Andrej Stefanov
Faculty of Engineering
IBU Skopje, North Macedonia
E–mail: andrejstefanov@ieee.org

***Abstract*—The paper investigates the retransmission efficiency given an end-to-end error control across the multihop routes. The efficiency is evaluated in the presence of interference and Ricean fading. Numerical examples illustrate the impact of frame size, transmit power, and number of hops on the retransmission efficiency.**

Keywords— underwater acoustic networks, retransmissions, efficiency.

I. Introduction

Underwater acoustic networks make it possible to gather ever increasing amounts of ocean data. This data stands to benefit a broad scope of studies that have not been previously possible including aquaculture monitoring, observations of marine animal forests, seismic activity and tsunami detection, tracking of ocean currents, and so on.

The challenge in the gathering of the ocean data is the unreliability of the underwater acoustic channel. Reliable underwater communication is challenging due to the narrow channel bandwidth, distance and frequency dependent attenuation, as well as, fading and interference. This necessitates the consideration of communication techniques aimed at improving the transmission reliability.

An established method of improving the transmission reliability and preventing frame losses are frame retransmissions. If error detection at the receiver indicates that the received frame contains errors, the frame is retransmitted. Of course, given retransmissions, it is of interest to consider the efficiency of communicating frames across the underwater acoustic network [1].

The paper considers the efficiency of a simple stop $\&$ wait retransmission protocol under the assumption that the network performs an end-to-end error control across the multihop route [2]. Hops take place between nearest neighbor bottom mounted nodes. All channels experience Ricean fading.

The organization of the paper is as follows. Section II investigates the retransmission efficiency of the multihop network. Numerical examples that illustrate the impact of the frame size, transmit power, and number of hops on the retransmission efficiency are presented in Section III. Section IV provides conclusions.

II. Retransmission Efficiency in Multihop Networks

The nodes forward the information using BPSK transmission and the demodulate and forward protocol. The route end-to-end frame error probability can be obtained as $p_{\text{route}} = 1 - (1 - p_b)^{L n_h}$ where p_b is the link bit error probability (BEP), n_h is the number of hops, and L is the frame size in bits.

In the scenario of a simple stop $\&$ wait retransmission protocol as an end-to-end error control, the efficiency is [1]

$$\eta = (1 - p_{\text{route}}) \frac{\frac{L}{R}}{t_f + 2t_p} \tag{1}$$

where R is the bit rate in bps, t_f is the frame duration and t_p is the propagation time. The frame duration is $t_f = L/R$ and the propagation time is $t_p = d/c$, where $c = 1500$ m/s is the speed of sound underwater. Note that, without the loss of generality, the acknowledgement duration is taken to be much smaller than the frame duration, $t_{\text{ack}} \ll t_f$, and that the frame overhead is taken to be much smaller than the frame itself, $L_o \ll L$. The efficiency becomes

$$\eta = (1 - p_b)^{L n_h} \left[1 + \frac{2dR}{cL}\right]^{-1}. \tag{2}$$

Given perfect channel state information at the receiver and flat Ricean fading [3], the BEP is [4]

$$p_b \leq \left(\frac{1 + \mathcal{K}}{1 + \mathcal{K} + \gamma(d,f)}\right) \exp\left(-\frac{\mathcal{K}\gamma(d,f)}{1 + \mathcal{K} + \gamma(d,f)}\right) \tag{3}$$

where γ is the signal to interference plus noise ratio (SINR). Given that the attenuation $A(d,f)$, noise $N(f)$ and interference $I(f)$ are constant over the operational bandwidth B, and f_o is the operating frequency, the SINR is [2]

$$\gamma(d, f_o) = \frac{P}{A(d,f_o)(N(f_o) + I(f_o))B}. \tag{4}$$

The interference is modeled as Gaussian with power spectral density [2]

$$I(f) \approx \frac{c_1 S}{A(2d,f)} + \frac{c_2 S}{A(3d,f)} \tag{5}$$

where $c_1 = c_2 = 6$ are constants.

III. Numerical Results

The results present the efficiency of the stop & wait retransmission protocol in underwater acoustic networks. Independent Ricean fading with $\mathcal{K} = 10$ is assumed for each channel between two neighboring nodes. The circular network area is $\mathcal{A} = 1000$ km^2. Fixed losses are neglected. The bandwidth is $B = 4$ kHz. The bit rate is $R = 1$ kbps. The spreading factor is $\kappa = 1.5$, the shipping activity factor is $s = 0.5$, and unless otherwise indicated, the wind speed is $w = 0$ m/s [5].

Figures 1 and 2 illustrate the retransmission efficiency for various frame sizes for the cases when the multihop route consists of $n_h = 2$ hops and $n_h = 4$ hops, respectively. Comparing the efficiency of the 2 hop route vs. the efficiency of the 4 hop route, say, in the case when the frame has $L = 500$ bits and there are $N = 1000$ nodes, we observe that the efficiency of the route with 2 hops is $\eta \approx 0.9$, while the efficiency of the route with 4 hops is $\eta \approx 0.8$.

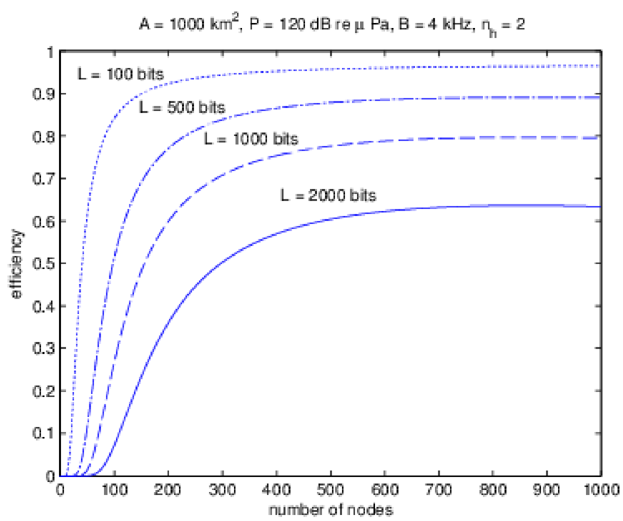

Fig. 1. Retransmission efficiency vs. the frame size for a route with $n_h = 2$ hops.

Figure 3 specifically focuses on the retransmission efficiency dependence on the number of hops n_h when the frame has $L = 1000$ bits. We observe that the efficiency decreases as n_h increases, say, for $N = 1000$ nodes it decreases from $\eta \approx 0.8$ for the 2 hop route to $\eta \approx 0.65$ when the route has 4 hops.

Figures 4 and 5 illustrate the retransmission efficiency for various transmit powers in the case when the route consists of $n_h = 2$ hops and $n_h = 4$ hops, respectively. The frame has $L = 1000$ bits. Comparing the efficiency with 2 hops and 4 hops, we observe that it may be possible to achieve the same efficiency by increasing the transmit power. Consider the case when when $N = 1000$ nodes. The efficiency achieved when the route has 2 hops is $\eta \gtrsim 0.9$ when $P = 125$ dB re μ Pa. It is possible to achieve similar efficiency $\eta \gtrsim 0.9$ when the route has 4 hops by increasing the transmit power to $P = 130$ dB re μ Pa.

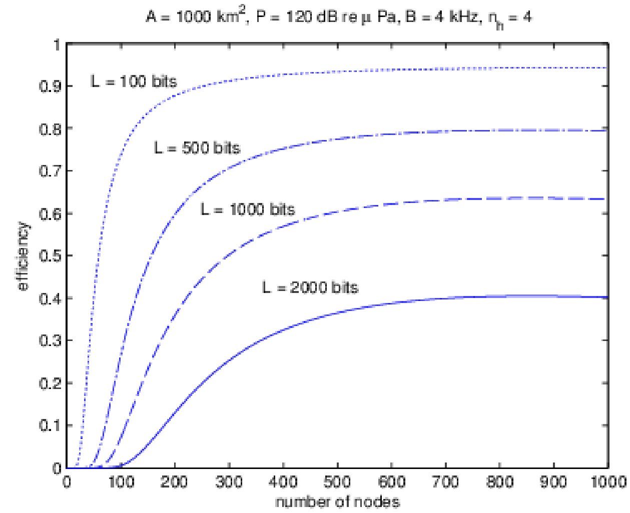

Fig. 2. Retransmission efficiency vs. the frame size for a route with $n_h = 4$ hops.

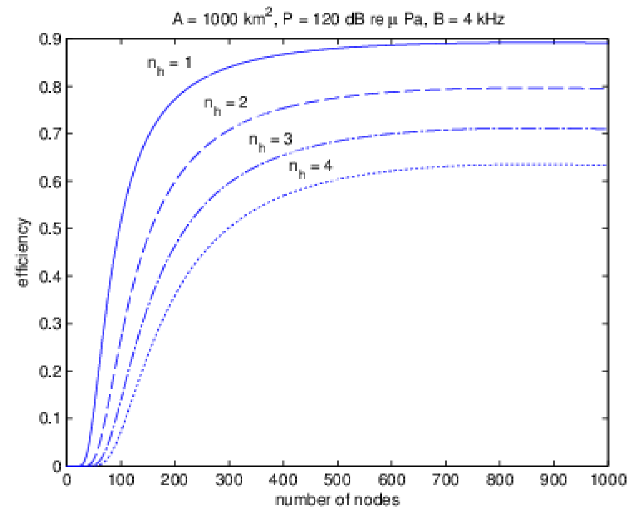

Fig. 3. Retransmission efficiency vs. the number of hops when $L = 1000$ bits.

Figure 6 investigates the impact that increasing wind speeds have on the retransmission efficency, for the case when the route has $n_h = 2$ hops and the frame has $L = 100$ bits. It can be readily observed that for the case when $N = 1000$ nodes, the efficiency decreases from $\eta \approx 0.95$ when the conditions are calm, that is, $w = 0$ m/s, to $\eta \approx 0.85$ when $w = 4$ m/s, and that it drops to only $\eta \approx 0.3$ when $w = 8$ m/s.

Furthermore, this behavior is even more pronounced for routes with more hops and larger frame sizes as observed from Figure 7 where the route has $n_h = 4$ hops and the frame has $L = 1000$ bits. For the case when $N = 1000$ nodes, the efficiency drops from $\eta \approx 0.65$ when $w = 0$ m/s to only $\eta \approx 0.35$ when $w = 2$ m/s.

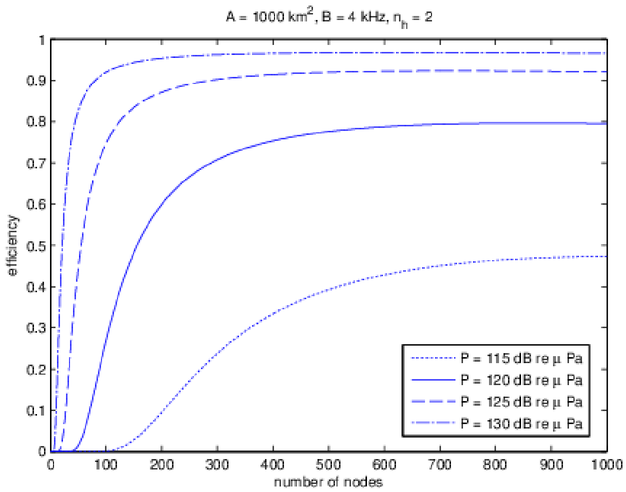

Fig. 4. Retransmission efficiency vs. the transmit power for a route with $n_h = 2$ hops when $L = 1000$ bits.

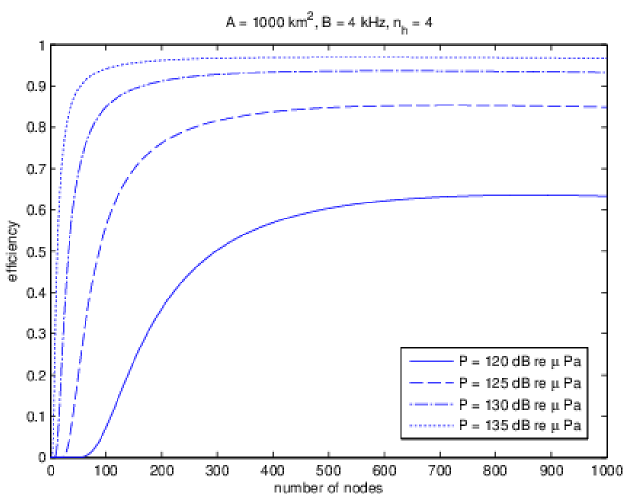

Fig. 5. Retransmission efficiency vs. the transmit power for a route with $n_h = 4$ hops when $L = 1000$ bits.

IV. Conclusions

The efficiency of the stop & wait retransmission protocol in underwater acoustic multihop networks was investigated comprehensively. The impact of frame size, number of hops, and transmit power on the retransmission efficiency was analyzed and illustrated through a number of numerical examples. It was observed that the retransmission efficiency decreases as the frame size and the number of hops increase. This is due the utilization of the simple demodulate and forward protocol with an end-to-end error control. On the other hand, it was observed that the retrasmission efficiency increases as the transmit power increases. This is due to the protocol constraint during frame transmissions along the multihop route [2]. Finally, it was observed that the retransmission efficiency decreases as the wind speed increases since the emergence of wind driven waves leads to less favorable propagation conditions.

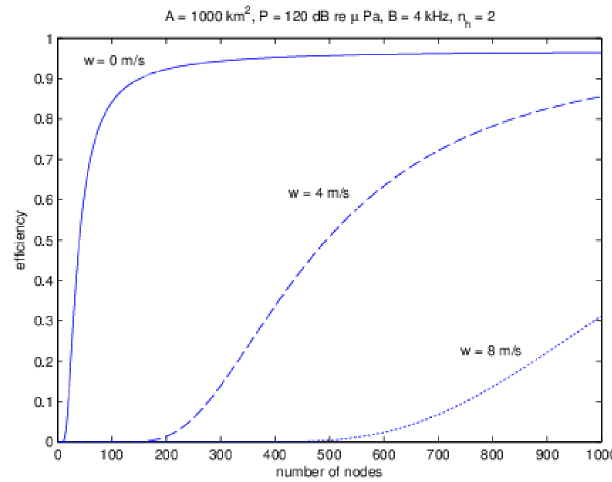

Fig. 6. Retransmission efficiency for different wind speeds for a route with $n_h = 2$ hops when $L = 100$ bits.

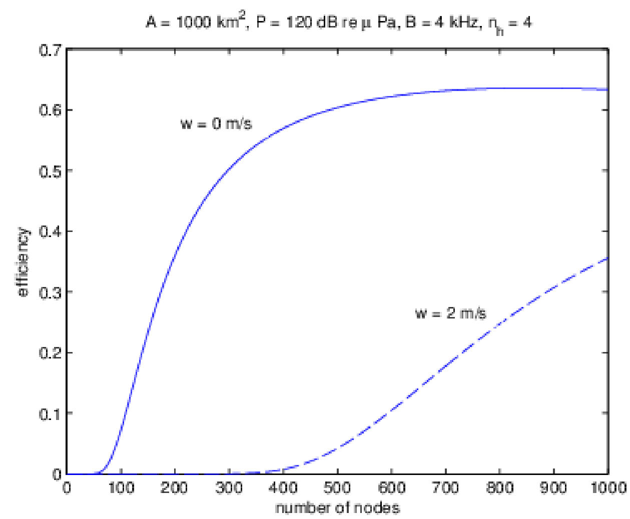

Fig. 7. Retransmission efficiency for different wind speeds for a route with $n_h = 4$ hops when $L = 1000$ bits.

References

[1] A. Leon-Garcia and I. Widjaja, "Communication Networks: Fundamental Concepts and Key Architectures," McGraw-Hill, 2003.

[2] A. Stefanov, "Impact of ARQ on the Performance of Underwater Acoustic Ad-Hoc Networks," in Proc. of International Conference on Smart Communications in Network Technologies, Vilanova i la Geltru, Spain, Jun. 2014.

[3] P. Qarabagi and M. Stojanovic, "Statistical Characterization and Computationally Efficient Modeling of a Class of Underwater Acoustic Communication Channels," IEEE Journal of Oceanic Engineering, vol. 38, no. 4, pp. 701–717, Oct. 2013.

[4] S. Benedetto and E. Biglieri, "Principles of Digital Transmission with Wireless Applications," Kluwer/Plenum, 1999.

[5] L. Berkhovskikh and Y. Lysanov, "Fundamentals of Ocean Acoustics," Springer, 1982.