Improved Estimation Procedure for Counting Neighbors in Underwater Networks

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Abstract- **In ad-hoc networks, at the beginning of network formation or later for routing purposes it is essential for a node to know how many neighbors it has. The capture effect, the effect of receiving a packet from a collision, can degrade the performance of the procedure of estimation of number of neighbors (ENN). The capture effect depends on different network parameters which are different in underwater communication networks (UCNs) than terrestrial communication networks (TCNs). Both electromagnetic (EM) and acoustic waves can be used in UCNs. Furthermore, underwater acoustic networks (UANs) have the problem of long propagation delays. These issues make the ENN procedure complicated. Here we propose an improved ENN procedure for UCNs as well as for TCNs which is not affected by the capture effect. The procedure requires fewer slots than earlier approaches and is much effective with packet reception time variations.**

I. INTRODUCTION

Large-scale wireless sensor networks can be deployed in civil and military applications for retrieving sensor data. Knowing the number of neighbors (nodes which are within direct transmission range of a particular node) is helpful in different ways. A number of sensors may be taken out or placed in the network at different times and some sensors can be damaged due to power failure or environmental factors. It is useful to know how many working sensors are currently available for maintenance purposes. An estimation procedure can be used in an ad-hoc network in the first instance when each node does not know how many other nodes are neighbors. Whenever a node wants to know the ids of the neighboring nodes [1, 2], the ENN is helpful because, in order to maximize the throughput for identification of the neighbors, the information about their number should be known by the receiving node. In addition, knowing the number of neighbors in a multi-hop wireless network allows the determination of such important factors as the probability of multi-hop connectivity, the number of hops needed to traverse a distance, and the energy consumption properties of a network [3].

For both underwater EM networks (UENs) [4] and underwater acoustic networks (UANs) [5, 6], signal propagation is different from other wireless networks. This complicates the development of protocols for underwater communications networks (UCNs). The capture effect [7, 8], which depends on the signal propagation, changes the statistical properties of the received packets and also causes the degradation of any procedure based on this number. In a UCN, due to absorption loss of the propagating wave, the capture effect is different from that in a TCN. Furthermore, due to propagation delays, usual estimation procedures cannot be directly used in long-delay-networks (LDNs) such as UANs.

Here, we propose a procedure for the estimation of the number of neighbors (ENN) which considers the capture effect and long-delay; therefore the procedure can operate on any type of network. This estimation procedure is termed as controlled framed slotted ALOHA (CFSA) in which the probing node broadcasts a frame length to its neighbors and then the nodes randomly transmit into the slots within a single frame. The ENN can be obtained from the occupancy of the empty slots in the frame. We compare our procedure with previous approaches [9, 10]. For given accuracy and probability CFSA performs better than those. We further show that when there is variation in the packet reception times as in UAN due to the variation in the signal propagation speed, CFSA performs better than other approaches.

The rest of the paper is organized as follows. In section 2, we describe the basic approach of the ENN. The capture effect and its influence on ENN are described in section 3. The CFSA approach and the effect of packet reception time variation on ENN are given in section 4 and 5 respectively. Finally we summarize in section 6.

II. BASIC APPROACH

From N neighbors, a probing node (base node) wants to estimate $\hat{N}$ within probability $(1-\alpha)$ and accuracy β [$N(1-\beta) \leqslant \hat{N} \leqslant N(1+\beta)$]. An ENN procedure is given in [10] based on probabilistic framed slotted ALOHA (PFSA) method. For a slotted protocol, we assume that the synchronization protocols of TCNs are sufficient for UENs. Current research [11] provides a synchronization protocol for LDNs. In the network there can be any number of neighbors, even thousands. As all the neighbors transmit at the same carrier frequency and with the same power, the maximum transmission distance, R, is the same for all the nodes in the network. In this procedure, the probing node broadcasts a frame size F (number of slots) and probability P towards the neighbors. The neighbors reply back to the probing node into a frame using P with pre-defined packets. A broadcast request and a reply constitute a *probe*. If N neighbors transmit once into a frame of size F, then the effective normalized offered load is $\rho_\xi = \frac{NP}{F}$, which is fixed to 1.6 in PFSA. In the replied frame, there are some empty, singleton and collision slots, which are represented by N_{0c}, N_{1c}

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and N_{cc} respectively, with n_{0c}, n_{1c} and n_{cc} being their particular instances (where variable without the subscript c represent the event without the capture effect, e.g. N_1 represents number of singleton slots without considering the capture effect). With these observed values, the probing node obtains the ENN. The probing and replies continue until the given probability and accuracy is achieved. Using N_{0c} in PFSA approach total slots needed is:

$$\eta = \frac{\left(e^{\rho_\xi} - \left(1 + P\rho_\xi\right)\right)Z^2}{\left(\beta\rho_\xi\right)^2} \tag{1}$$

where Z is the 1-α/2 percentile of unit normal distribution. As an example for α=0.01, Z=2.576.

For a LDN the frame starts at least after $2T$ time as shown in Figure 1, where T is the maximum propagation time. Guo et al. [12] use this constant maximum delay in every packet delivery, but for the handshaking purpose of a media access protocol. In our approach, the probing node broadcasts a time stamp to the neighbors so that, by comparing this time value with the reception time, the replying nodes can calculate the propagation time required to reach the probing node.

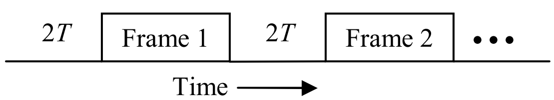


Figure 1. Framed ALOHA in a LDN.

III. AFFECT OF CAPTURE EFFECT ON ENN

The number of packets received or collided depends on the capture effect. We therefore cannot use those for the ENN procedure. In this section we show how much the capture effect can degrade the ENN procedure. Kodialam et al. [13] give emphasis on the collision slots for the ENN and they use (2) by solving for $\hat{N}$ using a numerical method.

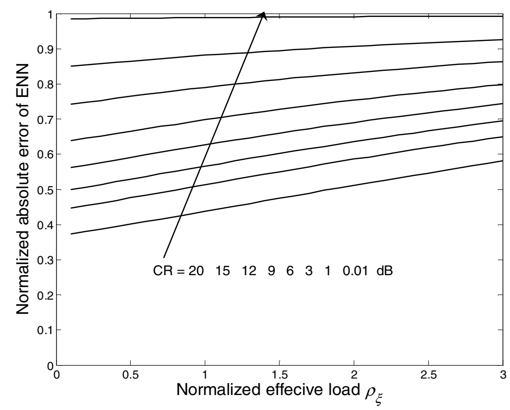
$$1 - \left(1 + \frac{\hat{N}P}{F}\right)e^{-\frac{\hat{N}P}{F}} - \frac{n_c}{F} = 0 \tag{2}$$

If we substitute the expected collision slots with the capture effect $E[n_{1c}]$, in place of n_c in (2) and solving for $\hat{N}$ we obtain a degraded ENN. Then the normalized absolute error of the ENN is a measure of the degradation, which is given by:

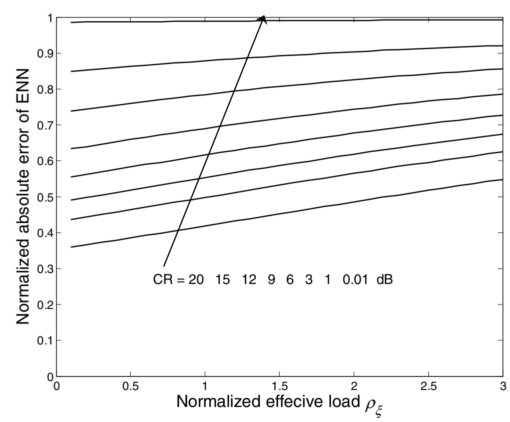
$$\theta = \frac{\left|N - \hat{N}\right|}{N} \tag{3}$$

Figure 2 shows the estimation errors using collision slots with the capture effect in 2D environment. The capture effect depends on the network parameters: dimensionality D, spreading loss factor k, absorption loss coefficient a and maximum transmission range R. Figure 2 (a) and (b) show the normalized absolute errors of ENN for UEN and UAN respectively by varying normalized effective load and the capture ratio (CR), where CR is the threshold power ratio of transmitting and interfering packets. From Figure 2 we see that the error increases with the increase of ρ_ξ and decrease of CR, since the capture effect phenomena increases with increasing ρ_ξ and with decreasing CR. In UCN for a low ρ_ξ there is 35% error for 20 dB CR. Hence N_{0c} (or N_0) can only be used for ENN, since it is independent of the capture effect.

A technique for estimating the number of operating sensors in a sensor network with a large number of neighbours is given by Budianu et al. [9]. It is based on the Good-Turing (GT) estimator of the missing mass described by Good [14]. The ENN obtained from the occupancy of the received slot. Hence the procedure is vulnerable to the capture effect.



(a)



(b)

Figure 2. Normalized absolute error of ENN using the number of collision slots for the ENN, D=2, F=100, N=1000, (a) UEN: k=6, a=1.5 dB/m, R=50 m, (b) UAN: k=1.5, a=0.05 dB/m, R= 2 km,

IV. Controlled Framed Slotted ALOHA (CFSA)

Unlike PFSA, here the offered load is adjusted according to the parameters of the estimation, where P=1 and the offered load is $\rho = \frac{N}{F}$. The estimation is obtained from:

$$\hat{N} = -F \ln\left(\frac{n_0}{F}\right) \tag{4}$$

The variance of the estimation is given by:

$$\delta_0^2 = N \frac{e^{\rho} - (1+\rho)}{\rho} \tag{5}$$

The ENN follows the normal distribution and using the interval estimation the total number of probes for CFSA can be found by:

$$\tau = \frac{\delta_0^2 Z^2}{N^2 \beta^2} = \frac{\left(e^{\rho_\xi} - \left(1 + P\rho_\xi\right)\right)Z^2}{\left(\beta\rho_\xi\right)^2} \tag{6}$$

When $\rho \to 0$ then $\tau \to 0$, but in reality, at least one frame is needed for the estimation. So the total number of probes for CFSA is $\lceil \tau \rceil$ and the total number of slots for ENN is $\eta = F\lceil \tau \rceil$. Simulation results for η are given in Figure 3 averaged from 20 observations for 99% confidence level. ρ is adjusted according to initial $\hat{N}$ and kept constant for all the probes. The zigzag patterns are for the ceiling function. The minimum value of η is shown as η_{min}.

τ needed for CFSA is shown in Figure 4. We see that η_{min} is obtained when τ=1. Hence, for the ENN, using CFSA requires only one probe considering the optimum offered load, ρ_o, which is obtained from solving (7) which provides η_{min}.

$$\frac{\left(e^{\rho} - (1+\rho)\right)Z^2}{\rho N \beta^2} - 1 = 0 \tag{7}$$

This optimum load is drawn in Figure 5. From the figure we see that when N increases optimum load also increases and when β increases optimum load decreases. Since the ENN is obtained from a single frame using the empty slots, there should be enough empty slots with high probability.

N_0 approaches the Poisson distribution with the parameter $\lambda_0 = Fe^{-\rho}$ [13, 15] when N and $F \to \infty$ and ρ is fixed. So, the probability of i empty slots in a frame is:

$$P[N_0 = i] = \frac{\lambda_0^i e^{-\lambda_0}}{i!} \tag{8}$$

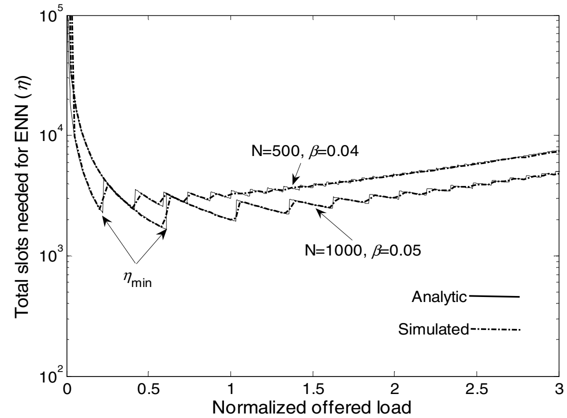


Figure 3. Total slots needed for varying offered load in CFSA approach.

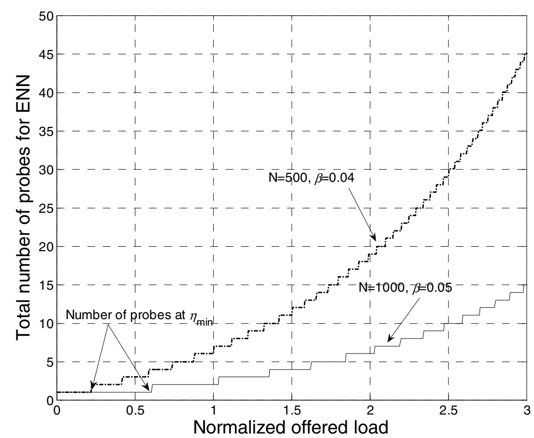


Figure 4. Total number of probes needed for CFSA approach.

The probability of no empty slots is

$$\begin{aligned} &P[N_0 = 0] = e^{-\lambda_0} \\ &\Rightarrow \lambda_0 = -\ln\left(P[N_0 = 0]\right) \\ &\Rightarrow \lambda_0 = -\ln(\varepsilon) \end{aligned} \tag{9}$$

with a very low probability $\left(P[N_0 = 0] = \varepsilon\right)$, where ε is a very small number. So, the value of ρ for which $P[N_0 = 0] = \varepsilon$ can be obtained from:

$$\begin{aligned} &\lambda_0 = Fe^{-\rho} \\ &\Rightarrow -\ln(\varepsilon) = Fe^{-\rho} \\ &\Rightarrow \rho = \ln\left(-\frac{F}{\ln(\varepsilon)}\right) \end{aligned} \tag{10}$$

Above equation provides us the maximum offered load ρ_m with which we can obtain N_0=0 with a very low probability ε.

Substituting $F = \frac{N}{\rho_o}$ in (10) we obtain:

$$\rho_m = \ln\left(-\frac{N}{\rho_o \ln(\varepsilon)}\right) \tag{11}$$

By varying N and β and using (11) we obtain Figure 6. We observe that maximum ρ is much larger than ρ_o. Hence, we deduce that the probability of obtaining ENN using CFSA is almost 1. As ρ_o lies in the denominator of (11) the curves follow the reverse order in Figure 6 than in Figure 5 with change in β.

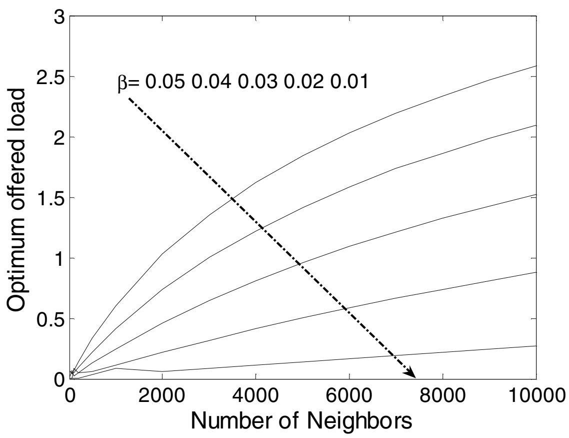


Figure 5. Optimum offered load for CFSA.

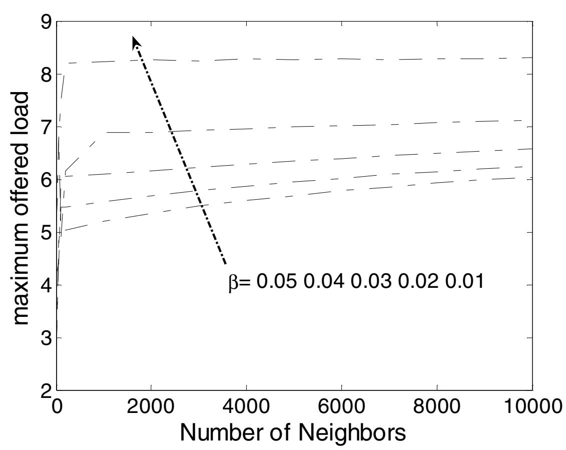


Figure 6. Maximum offered load for CFSA, ε=.0001.

η_{min} is plotted in Figure 7 for varying N using CFSA along with η needed using PFSA and GT approach for different values of β and fixed probability of 0.99. We observe that for only large β PFSA is better than CFSA. Although GT method is vulnerable to the capture effect we also plotted total slots needed using that method. GT method is proportional to N so it increases rapidly as N increases. We see that CFSA performs better than other approaches most of the time.

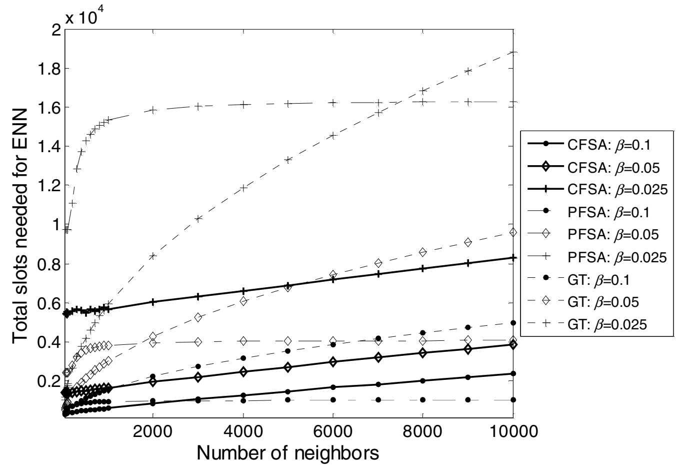


Figure 7. Comparison of CFSA with other approaches.

V. Packet Receive Time Variation

Commonly, any slotted approach assumes that the packet size is equal to the slot size and a packet falls entirely into a slot. However, if there is a time variation in the receive time of a packet in the base station, then the entire packet might not fall inside the slot. This time variation is called received jitter. The sources of error for this jitter include propagation delay variation, encoding-decoding time, and interrupt handling time, as fully described in [11]. This received jitter generally follows a normal distribution [16] for a TCN. In this work, we consider the same distribution for the received jitter in LDNs. In UANs, as the dominant factor for received jitter is the variation of the propagation delays, the distribution of receive time jitter depends on the distribution of propagation delay.

This problem of receive jitter can be reduced by introducing guard time into a slot which is an extra space into a slot to accommodate for the varying packet reception time. Here we formulate our problem in a different way. The decision region for the slot emptiness is reduced to a time less than the slot size which resides equally apart from the middle of a slot. The regions in a slot apart from the decision region can be regarded as guard time. The slot structure is given in Figure 8.

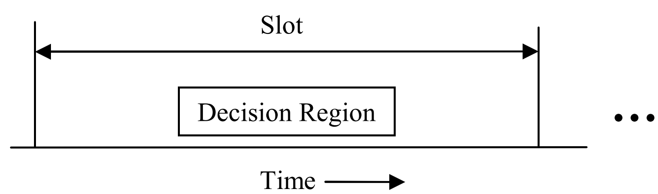
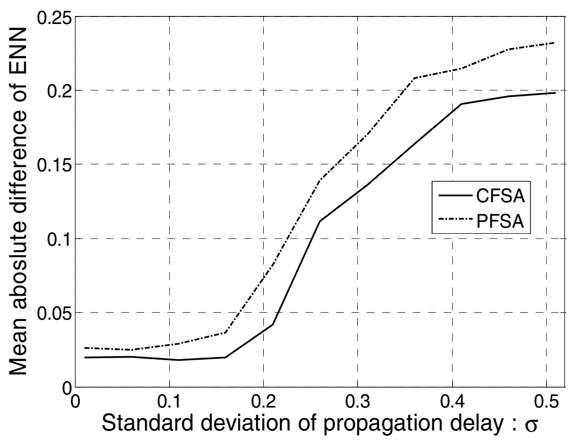
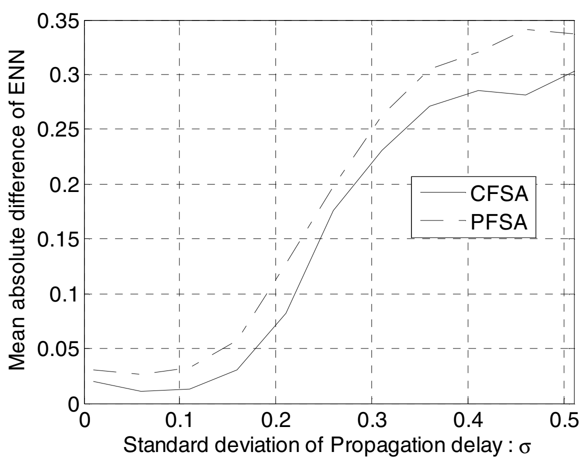


Figure 8. Slot with decision region.

Assuming a normal delay variation with standard deviation σ and decision region time φ both normalized by packet time, mean absolute difference θ of ENN plotted for CFSA and PFSA are shown in Figure 9 averaged from 20 Monte Carlo runs. We observe that, when the decision region increases the error in the estimation also increases. This is because, due to increase in decision region more slots are taken as singleton or collision slots even though the slots are empty. The critical values of σ for which θ lies below the value of β are for CFSA 0.22 and 0.175 for Figure 9 (a) and (b) respectively. The critical values for PFSA are 0.175 and 0.15. We can say that CFSA performs better than the other with receive time jitter.



(a)



(b)

Figure 9. Effect of receive time jitter in ENN, (a) N=100, β=.05, φ=0.2, α=0.01 ; (b) N=100, β =.05, φ=0.3, α=0.01;

VI. CONCLUSION

Here we propose an improved estimation procedure for counting number of neighbors in a UCN, where only one probe is needed for ENN that eventually helps for LDN where some time is wasted as waiting time in each frame. The procedure in most cases takes less slots than earlier approaches and also robust in presence of receive time jitter. Finding an optimum decision region for ENN with receive jitter can be a case of future work.

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