Adaptive Holding time and Depth-Based Routing for Underwater Wireless Sensor Networks

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ABSTRACT

In Underwater Wireless Sensor Networks (UWSNs), traditional enhancements of Depth-Based Routing (DBR) scheme rely either on increasing the network overhead or on the adoption of offline localization schemes to improve the network performance in terms of energy consumption, end-to-end delay or network throughput. Unfortunately, localization based techniques are very hard to implement in practice. In this work we show some preliminary results about the performance of a routing scheme called Adaptive Holding time and Depth-based routing (AHD) that we propose to dynamically adapt DBR configuration parameters. Specifically, we show a set of simulation experiments that suggest that networks implementing AHD show a reduced energy consumption with respect to those implementing the standard version of DBR. Simulations are performed by using our simulation library [8] of DBR [12] developed for the simulator AquaSim-Next Generation (NG) underwater simulator, which is based on Network Simulator-3 (NS-3) [11]. The characteristics of this library (detailed representation of cross-layer communications and operation modes of the modems) allows us an accurate prediction of the performance improvement of AHD with respect to standard DBR.

KEYWORDS

Underwater Sensor Networks, Routing protocols, Depth-based routing, Energy efficienct routing

1 INTRODUCTION

In the recent years, UWSNs have emerged as a major research domain due to their applications for the management of seabed, pollution monitoring, seismic monitoring etc. The performance of the applications of UWSNs largely depends on the efficient utilization of acoustic signal as a transmission link. Previous works [1] in the domain of underwater acoustic communication can be classified according to their ISO/OSI level, e.g., physical, Medium Access Control (MAC) and network layer. Depth Based Routing protocol (DBR) is a network-layer protocol that uses some cross-layer features. One of its strengths is that it is a localisation-free routing [5] protocol, i.e., it requires only the knowledge of the depth of the nodes. Despite this limited amount of information, DBR is capable of tackling the typical challenges of UWSNs such as the node mobility and the large transmission losses. Localisation-free routing protocols work in a fully distributed manner, specifically DBR [12] capitalizes the depth information of nodes to successfully transmit data from the source node to the on-surface sink. For determining the depth information of nodes, pressure based sensors are employed.

For performance evaluation of sensor networks, various simulation environments has been proposed. During literature review, we passed through the models designed for the computation of the network energy consumption and different methods of energy harvesting in sensor networks. Erol et.al [6] provide the model to study the phenomenon of energy packet networks and discuss the relation between the energy flow and data packet transmission. In [3], authors propose an algebraic framework to predict the network connectivity and communication interference in mobile-adhoc networks. Node mobility has been taken into account in order to perform the behavioral analysis for wireless networks. In another work, Bujari et.al [4] propose an analytical model to analyze the well-known congestion avoidance mechanisms in large-scale networks, in which they have evaluated the performance of the mechanisms through various metrics e.g. average queue length, expected queuing time and system throughput etc.

2 PROBLEM MOTIVATION AND CONTRIBUTION

DBR considers the depth difference between the sender and the receiver node for the selection of the forwarder. The main mechanism adopted by DBR is rather simple: when a node receives a packet, it computes the depth difference between itself and the sender. If this value is below the depth threshold, then the packet is discarded. Otherwise, the node waits for a time (called holding time) which is proportional to the depth difference. In this way, nodes that are closer to the surface are more likely selected to be forwarders. In this context, we have to set two parameters: the depth threshold and the multiplicative factor for the computation of the holding time. Lower values of these parameters increase the total number of transmissions in the network and hence the expected energy consumption for successfully delivered packet, whereas larger values reduce the packet delivery ratio and the end-to-end packet delay. Moreover, it can be seen from previous works that the optimal value for these parameters strongly depend on the node density of the network. In this work, we propose AHD, a technique that allows nodes to dynamically estimate the node density in the region of the UWSNs where they lay and adapt their configuration parameters in order to achieve a higher network efficiency. The protocol shows its benefits in networks where the nodes are distributed in a non-homogeneous way.

3 SYSTEM MODEL

We consider a 3D network providing the nodes deployed with the uniform random distribution. On the physical layer of acoustic communication, we employ Thorp's formula [7] in order to compute the total attenuation of acoustic signal as follows:

$$10logA(l, f) = k * 10log(l) + l * 10log(\alpha(f)), \tag{1}$$

In the above equation, l denotes the euclidean distance between the sender and receiver, f is the frequency of the signal, k is the spreading coefficient while $\alpha(f)$ shows the total absorption loss of

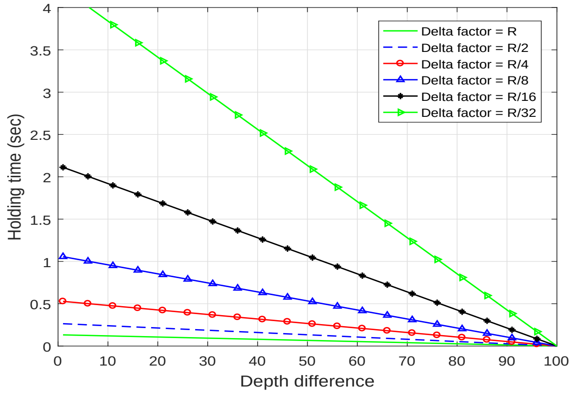

Figure 1: Variation in duration of holding time due to changes in delta factor

signal. We estimate the total noise loss *NL* by combining the four components below:

$$NL = N_t(f) + N_s(f) + N_w(f) + N_{th}(f)\,. \tag{2}$$

where $(N_w(f))$ denotes the wind factor, $(N_s(f))$ is the shipping factor, $(N_{th}(f))$ is the thermal factor and the $(N_t(f))$ is the turbulence factor. We use the BroadcastMac [10] protocol for the medium access control.

In our network, total end-to-end delay is composed of multiple components. Holding time delay of the node and propagation delay are the two major components moreover the progation delay depends on the speed of the acoustic signal in water. Speed of the accoustic signal is denoted by q which can be computed as follows [2]:

$$q = 1449.05 + 45.7t - 5.21t^2 + 0.23t^3 + (1.333 - 0.126t + 0.009t^2)$$
$$(S - 35) + 16.3z + 0.18z^2, \tag{3}$$

$$t = T/10. \tag{4}$$

where T is the temperature in $^\circ C$, S is salinity and z is the depth in km.

4 METHODOLOGY OF AHD

The protocol operation has been separated into the sequential parts. First of all, nodes receive the packets from all the neighbors and check the stored depth information of the neighbors in the header of the received packets. Nodes start to count the number of their low-depth neighbours along with averaging their depth differences. Then, starting from the high depth region, all the nodes transmit their computed δ factor and the neighbour count in the packet header, which is ultimately used by receivers to decide about data forwarding.

Adaptive holding time computation. In this work, we follow the receiver-based approach of DBR with the following modifications:

- Nodes compute an estimate of the number of their lower depth Neighbours (N) by checking the depth information stored in the packets received from them up to a certain time. N is then further added to the header of the packets sent by the node.
- The receiver uses the received value of N to compute their own δ factor and then the holding time for the received packet.

The holding time is computed on the basis of the formula given below:

$$Holding\_time(d, N) = \left(\frac{2\tau}{\delta}\right) * (T - d)\ \text{, where}\ \delta = T/N \tag{5}$$

where N is the estimated number of lower-depth neighbours of the sender node, τ is a maximum propagation delay for direct communication in the network, d is the depth difference between sender and receiver, and T is the maximum transmission range of any node. In our scheme, δ depends on the value of N thanks to which the receiver is able to estimate the neighbor density around itself during the competition for the packet forwarding. If N is high, this implies a high neighbor density around itself, and hence this results in low value of δ factor as well as a large scaling of the holding time for the received packet. Due to the large scaling of the holding time, redundant transmissions by the hidden terminals are reduced. As a consequence, this leads to a decrease in total network energy consumption and an increase of the network lifetime. On the contrary, low values of N results in the low scaling of the holding time and the fast retransmission.

Average-based Depth threshold. We also propose the adoption of an average-based depth threshold (AD_{th}) which is determined by computing the average of depth differences between a sender node and its lower depth neighbors. Instead of using a fixed depth threshold as in DBR, receiver nodes find their eligibility for data forwarding by using the AD_{th} stored by the sender node. Formally, AD_{th} is computed as follows:

$$AD_{th} = \left(\sum_{i=1}^{N} d_i\right)/N\ \text{, where}\ AD_{th} > D_{min} \tag{6}$$

D_{min} is the minimum limit for AD_{th} to avoid the flooding, whereas d_i is the depth difference of sender and ith receiver node. Each node computes the respective AD_{th} for its receivers by averaging their depth differences and stores this information in the header of transmitted packets. The information is used by a receiver to find its eligibility for data forwarding. In case of high neighbor density, this mechanism further decreases the number of total transmissions in the network due to increase in AD_{th} while it maintains the high packet delivery ratio.

5 RESULTS AND DISCUSSION

Simulation have been performed in underwater specialized simulator AquaSim-NG [9]. In our simulation settings, we took a network of size 500m ×500m ×500m adding that the number of deployed node varies from 300 to 700. For our initial results, we took fixed transmission range and no mobility for nodes. We compared our results with DBR and computed the important performance metrics of total energy consumption, end-to-end delay and packet delivery ratio of the network. In figure 3, we show that the total energy consumption decreases for high network density scenario which is also providing maximum packet delivery ratio. However, for less

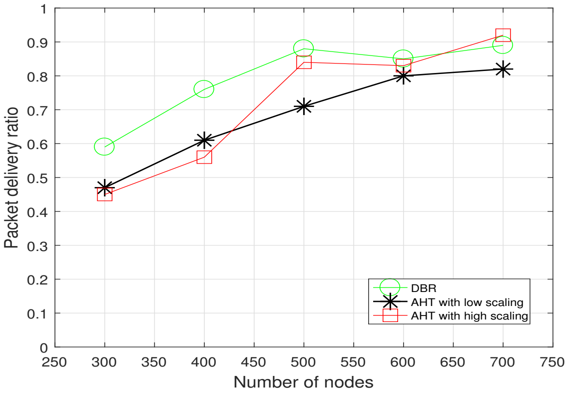

Figure 2: Packet delivery ratio of network for various number of deployed nodes

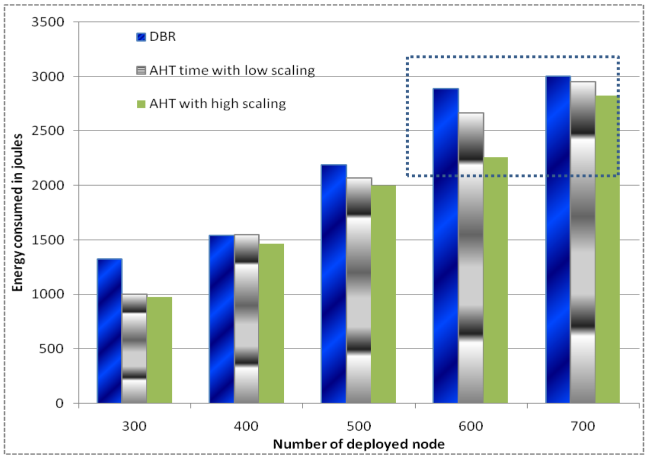

Figure 3: Total network energy consumption for various number of deployed nodes

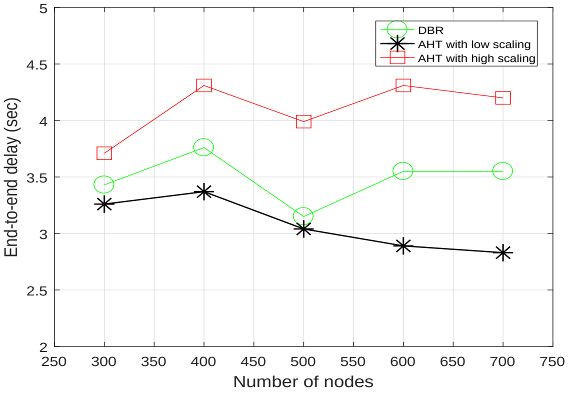

Figure 4: End-to-end delay of network for various number of deployed nodes

number of deployed nodes, there is a little improvement as it results due to minimized hidden terminals in lower network density. End-to end delay is the trade-off parameter which is increased due to high scaling of δ factor. Figure 2 shows that although the packet delivery ratio of our scheme is lower than of DBR for less number of deployed nodes, however, it is ignored as the optimal number of deployed nodes are preferred by which maximum packet delivery ratio could be achieved. Therefore, our scheme performs much better for the dense conditions. Figure 4 demonstrates that the end-to-end delay for high scaled δ factor is higher than the other two schemes which acts as a trade-off factor to minimze energy consumption of the network.

6 CONCLUSION

In the domain of localization-free routing protocols, most novel routing protocols ignore the basic rules of design which make them a little bit unrealistic. These protocols usually employ offline localization schemes which increase the energy efficiency of the network, however increase the network deployment cost. We devise AHD routing protocol, which decreases the total energy consumption of the network at the cost of end–to-end delay specifically for the highly dense networks. We provide its multiple versions by discussing the high scaling and low scaling cases of the δ factor. In the future work, we aim to tackle the mobility issues of our scheme.

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