Power-Aware Routing for Underwater Wireless Sensor Network

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Abstract. Water covers more than 70 % of the entire planet, contains much of its natural resources. With the increasing use of underwater sensors for the exploitation and monitoring of vast underwater resources, underwater wireless sensor network (UWSN), mostly based on acoustic transmission technologies, have been developing steadily in terms of operation range and data throughput. In an energy-constrained underwater system environment it is very important to find ways to improve the life expectancy of the sensors. Compared to the sensors of a terrestrial Ad Hoc Wireless Sensor Network (WSN), underwater sensors cannot use solar energy to recharge the batteries, and it is difficult to replace the batteries in the sensors. This paper reviews the research progress made to date in the area of energy consumption in underwater sensor networks (UWSN) and concentrates on developing routing algorithms that support energy efficiency. These algorithms are designed to carry out data communication while prolonging the operation time of WSNs.

Keywords: Sensor · Under water · Routing · Linear programming

1 Introduction

Nowadays few underwater sensor networks exist because commercially available underwater acoustic modems are too costly and energy inefficient to be practical for this applications. The commercially available acoustic modems provide data rates ranging from 100 bps to about 40 Kbps, and they have an operating range of up to a few km and an operating depth in the range of thousands of meters. The cost of a single commercial underwater acoustic modem is at least a few thousand US dollars. It can be concluded that Micro-modem is much more advanced for physical layer research. However, the modem of J. Willis et al. consumes less power and has a much simpler design; although this modem is designed only for short range communication (50–500 m).

Underwater acoustic transmission has been heavily studied during the last decade. Recently, significant advances in routing protocols for underwater sensor networks have been achieved. Good surveys reviewing the recent advances and challenges in underwater sensor networks can be found in the Section below.

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2 Routing Protocols in UWSNs

DBR (Depth Based routing) [7] routes the messages from the bottom of the ocean to the surface using only depth information. The depth of the source node and the depth of the forwarder are attached to the packet, that way, an intermediate node forwards a packet only if its depth difference with the forwarder is higher than a certain predefined threshold. In addition, an intermediate node has to wait to forward a packet for a certain amount of time called the holding time during which, if a copy of the packet is received, the transmission is cancelled. This way, the protocol avoids flooding and the routing can be made without exact location information.

A similar algorithm to DBR is DSR (Direction-Sensitive Routing) [8]. This algorithm utilizes a fuzzy logic inference system to decide which nodes should forward a packet based on the distance and angle between two neighbouring sensor nodes, and the remaining energy left in the sensor node. In addition, in order to save energy, the protocol restricts the forwarding of the packet when the broadcast tree grows larger than a specified tree level. According to the authors, DSR can achieve the same packet delivery ratio as DBR but with lower end-to-end delay and less energy consumption.

In [9] a centralized routing protocol based on geographic information is proposed. The master node computes the topology and the routing paths. The main drawback of this protocol lies in the complexity of the algorithm that computes the topology and the routing paths, since it is NP-complete.

Minimum Cost Clustering Protocol (MCCP) is a distributed clustering protocol proposed in [10]. The authors propose a cluster-centric cost-based optimization problem for the cluster formation. Although cluster-heads have the ability to send the data in a multi-hop manner to reach the sink, all nodes are supposed to be able to reach the sink. The cluster-head selection algorithm does not assure that the cluster-heads far away from the sink are able to relay their data to other cluster-heads.

EDETA (Energy-efficient aDaptive hiErarchical and robusT Architecture) is a routing protocol originally proposed for WSN [11, 12] and recently adapted to UWSN. It is a hierarchical protocol and nodes arrange themselves in clusters with one of them acting as a cluster-head (CH). The CHs form a tree structure between themselves in order to send the collected and aggregated data from the other nodes to the sink in a multi-hop manner. The protocol supports more than one sink in order to provide more scalability and some fault tolerant mechanisms.

Operation of the EDETA protocol is divided into two phases (i) the initialization phase and (ii) the normal operation phase. During the initialization phase, clustering is done and cluster-heads are elected.

During the normal operation phase, the nodes send their data periodically, at their scheduled times, to their CHs. Finally, cluster-heads send their data to their parents until the data reaches the sink.

In this protocol, similarly to the LEACH election mechanism [13], the CH election mechanism is distributed among the nodes in the network. Moreover, in order to distribute the energy consumption, the network structure is broken up after a certain amount of time and the initialization phase starts again. An enhanced version of

EDETA, called EDETA-e (EDETA-enhanced), also allows the designers of the network to accurately plan and choose nodes acting as CHs. In this variant of the protocol the initialization phase is done only once.

3 Mathematical Model for the Routing Problem in UWSNs

A sensor network is modeled as $G(V,L)$, where V be the set of nodes and L be the set of links between the nodes. Each node i has the initial battery energy of E_i, and the amount of energy consumed in transmitting a packet across link $L_{(i,j)}$ is $el_{i,j}$. Let Q_i be the amount of traffic generated or sink at Node i. Let T be the time until the first sensor node run out of energy. Let $q_{i,j}$ be traffic on the link $L_{(i,j)}$ during the time T. The problem is formulated to maximize the lifetime of the sensor networks.

Maximize: T

Subject to:

$$\sum_{j=1}^{N} q_{j,i} + QT = \sum_{j=0}^{N} q_{i,j} : \forall i \in [1 \ldots N] \tag{1}$$

$$\sum_{i=1}^{n} q_{i,j} el_{i,j} <= E_i : \forall i \in [1 \ldots n]$$

$$\sum_{i=1}^{n} q_{i,0} = Qn$$

$$q_{i,j} >= 0 : \forall i,j \in [1 \ldots n]$$

4 Heuristic Method for the Routing Problem

The heuristic algorithm (RE_heuristic) is given as below:

RE_heuristic:

In every round of data transmission to the base station, select a path in order to minimize the total of the reverse of residual energy of all sensor nodes in the path.

Let us define a weight for a link on any path as:

$$W(i) = \frac{1}{e(j)}$$

where e(j) is the remaining energy of source Node j on the link. Given a source node sand a destination node d, find a simple path Π *from s to d that minimizes the total weight by all links participating in the data transmission.*

$$\sum_{i \in \Pi - d} W(i) \textit{ is minimized}$$

(End of algorithm).

5 Simulation Results

In the first set of simulations, the performance of RE_heuristic is compared to the solution given by Formulation (1). In the simulations, 100 random 50-node sensor networks are generated. Each node begins with 1 J of energy. The network settings for the simulations in this section are given below. The energy model was used in [1, 2, 6].

Network size $(100m \times 100m)$	
Base station $(50m, 200m)$	
Number of sensor nodes	100 nodes
Position of sensor nodes: Uniform placed in the area	
Energy model: E_{elec} =50*10^{-9} J, ε_{fs} =10*10^{-12} J/bit/m^2 and ε_{mp} =0.0013*10^{-12} J/bit/m^4	

Figure 1 shows the ratio of the number of rounds of RE_chain and the Linear Programming solution of Formulation (1). From the simulation result, it can be said that RE_chain performs within 1 % of the Linear Programming solution.

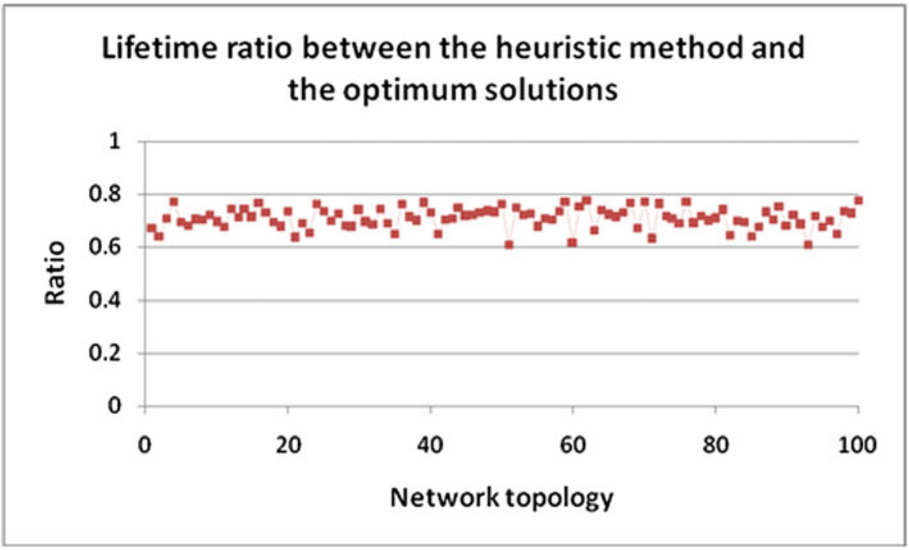

Fig. 1. Ratio of the number of rounds between the heuristic method and the optimum solution

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