Ad Hoc Networks 11 (2013) 2301–2312

Contents lists available at SciVerse ScienceDirect

Ad Hoc Networks

journal homepage: www.elsevier.com/locate/adhoc

# Towards efficient dynamic surface gateway deployment for underwater network

Saleh Ibrahim, Jun Liu *, Manal Al-Bzoor, Jun-Hong Cui, Reda Ammar

*CSE Dept., University of Connecticut, Storrs, CT 06269, USA*

ARTICLE INFO

*Article history:*
Received 6 November 2012
Received in revised form 26 March 2013
Accepted 28 May 2013
Available online 6 June 2013

*Keywords:*
UWSN
Gateway deployment
Optimization framework

ABSTRACT

In underwater acoustic sensor network, deploying multiple surface-level radio capable gateways is an efficient way to alleviate the burdens of high propagation delay and high error probability during transmission. However, the locations of gateways need to be carefully selected to maximize the benefit in a cost-effective way. In this paper, we present our formulation of the surface gateway deployment problem as an integer linear programming (ILP) and we solve the problem with heuristic approaches to provide a realtime solution for large scale deployment problems. By applying the proposed heuristic algorithms to a variety of deployment scenarios, we show that they are nearly optimal for practical cases, which opens the door for dynamic deployment. Therefore, we extend our solution to a dynamic case and propose a modified framework that integrates Aqua-sim, a NS2-based underwater wireless sensor network simulator. Our simulation result shows the benefits of dynamic gateway redeployment over static deployment.



## 1. Introduction

Recently, Underwater Wireless Sensor Networks (UWSN) have emerged as a new alternative technology enabling underwater monitoring and exploration applications, including scientific, commercial and military applications [1–5]. At the same time, it also brings many technical challenges due to its special character of acoustic communication, and water environment, such as long and propagation delay, high error probability, limited power supply [3–7].

One way to alleviate the effect of the high propagation delay introduced by acoustic communications in underwater sensor networks is to deploy multiple surface-level gateways. Fig. 1 illustrates an underwater sensor network with multiple surface gateways. In the sensor network, each sensor node can monitor and detect environmental events locally and then transfer these measurements, through the network, to a surface gateway node (which is also referred to as a sink for the UWSN), which then relays data to the control station. Instead of having to use long underwater paths to reach a unique surface sink, a multiple-sink underwater sensor network differs from single sink networks in that nodes can send data packets towards a nearby surface-level gateway, as illustrated in Fig. 1. A surface gateway then uses radio waves to forward packets to the control station. Considering that electromagnetic wave propagation is orders of magnitude faster than acoustic wave propagation, it is safe to consider the radio propagation delay from a surface gateway to the control station negligible. The same can be said about energy consumption since acoustic communications consume much more energy than radio communications [5]. Accordingly, all the surface-level gateways (or sinks) along with the control station form one *virtual sink*.

In our previous work [8], we studied in detail the factors and benefits of such an architecture and formulated the gateway optimal deployment as an integer linear programming (ILP) problem. In this paper, we demonstrate the

* Corresponding author.
*E-mail addresses:* saleh@engr.uconn.edu (S. Ibrahim), jul08003@engr.uconn.edu (J. Liu), mha09004@engr.uconn.edu (M. Al-Bzoor), jcui@engr.uconn.edu (J.-H. Cui), reda@engr.uconn.edu (R. Ammar).

1570-8705/$ - see front matter © 2013 Elsevier B.V. All rights reserved.
http://dx.doi.org/10.1016/j.adhoc.2013.05.011

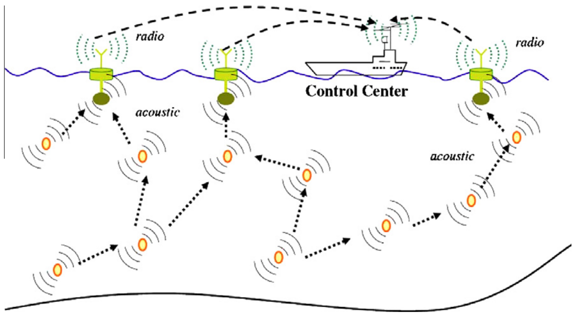


**Fig. 1.** UWSN with multiple surface gateways.

performance of heuristic solutions to the gateway optimal deployment problem and show that high-performance solutions can be efficiently found in polynomial time, enabling the realtime solution of large-scale deployment problems and opening the door to investigating the dynamic re-deployment of gateway nodes. Therefore, we show how our gateway deployment optimization framework can be practically extended to a dynamic redeployment scenario by incorporating simulation-obtained performance parameters, and shows its benefit over static deployment.

The work presented in this work is organized as follows: first, Section 2 presents related works and Section 3 introduces our general framework, then in Section 4, we show the heuristic approaches. Next, Section 5 demonstrates the dynamic deployment. Finally, Section 6 summarizes our contributions and suggests some directions for future work.

## 2. Related work

In the literature, a variety of node deployment strategies for underwater sensor networks have been presented. [9,10] have identified two types of UWSN deployments. In a *Two-Dimensional UWSN*, sensor nodes are anchored to the bottom of the ocean. Underwater sensors may be organized in a cluster-based architecture, and be interconnected to one or more underwater gateways by means of a mainly horizontal acoustic data links. Underwater gateways relay data collected by sensors to a surface station through a mainly vertical acoustic link. In a *Three-Dimensional UWSN*, sensors float at different depths in order to observe phenomena that cannot be adequately observed by means of ocean bottom sensor nodes. These floating sensors can either be anchored to the sea bottom or hanging from surface buoys by means of variable length strings. The depth of a sensor node can then be regulated by releasing or retracting its anchor string.

According to [9], optimal deployment of 2-D UWSNs involves determining the minimum number of sensors and underwater gateways to achieve a target sensing coverage and communication connectivity requirements. They also address the question of determining the surface deployment area in order that the sensor nodes land within a certain target bottom area. For 3-D UWSNs, the authors suggested three deployment strategies: 3D-random, bottom-random, and bottom-grid. In a *3D-random* deployment, underwater nodes anchor themselves at random ocean bottom locations and then float at random depths. In *bottom-random* deployment, underwater nodes anchor themselves at random ocean bottom locations then information about their locations are used to calculate the optimal depth at which each node should float in order to satisfy sensing and communication coverage. In a bottom-grid deployment, a AUV is used to anchor underwater sensor nodes at predetermined locations, and each sensor is assigned its desired depth in order to achieve the target coverage ratio.

The question of relay node deployment optimization has been the focus of a number of research efforts. [11] presented a MIP framework for describing the relay deployment optimization problem. Static link-scheduling and routing were used to control medium access to avoid collisions and to route data from sensors to the surface sink. In their formulation, the authors assumed that packets would have to travel from their respective sources to the sink within a single period of the schedule, resulting in unnecessarily long schedule periods.

An interesting idea for improving UWSN energy efficiency is the use of mobile data collectors. The idea of mobile sinks or mobile data collectors has been proposed in literature both for underwater sensor networks [12,13]. When the application of the sensor network is not a realtime application, data can be stored at sensor nodes until a mobile data collector is in the vicinity. Data collectors make rounds traversing the sensor network following a path determined through an optimization process. A WSN architecture that relies on mobile data collectors have one main advantage, namely reducing the communication-related energy consumption of sensor nodes, thus prolonging the sensors lifetime.

The redeployment issue has been addressed by some earlier research. [14] illustrated the need for redeployment due to the continuing drift of sensor nodes away from the required sensing coverage area due to their passive mobility. The authors assumed a random walk model and considered only replacing lost sensors as a corrective redeployment strategy. [15] addressed the problem of repositioning underwater sensors in order to improve the collective coverage of the network. In addition to minimizing the total cost of moving all sensors during the repositioning process, they also considered the problem of minimizing the maximal cost of repositioning any one set sensors assigned to a single AUV, in order to avoid depleting the feul of one AUV much earlier than others during the repositioning process.

Our work differs from all the above in addressing the multiple sink deployment problem. It formulates the problem by taking delay and energy as the major objective functions with multiple cost and performance related constraints, and solves the problem using heuristic approaches and extends our solution to a dynamic case.

## 3. Problem formulation

We apply the same problem setting described in [8], which assumes that there is a pre-existing underwater