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An adaptive routing protocol in underwater sparse acoustic sensor networks

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A B S T R A C T

Underwater acoustic sensor network (UASN) is a promising technique, which will facilitate a wide range of aquatic applications. However, because of adverse underwater environments, UASN faces grand challenges and problems such as limited bandwidth, node movement, long propagation delay, three-dimension deployment, energy-constraint, expensive manufacture and deployment costs. In order to address these problems and challenges, in this paper we propose an adaptive hop-by-hop vector-based forwarding routing protocol on the basis of HH-VBF (called AHH-VBF). Firstly, during the transmission process, the radius of virtual pipeline is adaptively changed hop by hop to restrict the forwarding range of packets so that the transmission reliability can be guaranteed effectively in the sparse sensor region and the duplicated packets can be reduced in the dense sensor region; secondly, the transmission power level is also adaptively adjusted hop by hop in cross-layer fashion so that the energy-efficiency can be improved effectively; thirdly, forwarding nodes are selected based on the distance from current node to destination node so that the end-to-end delays are reduced effectively. Eventually, we propose two metrics: propagation deviation factor and effective neighbor number, to evaluate the network performance of AHH-VBF. We conduct extensive simulations using ns-3 simulator and perform theoretical analyses to evaluate the network performance. Our experimental results verified that the AHH-VBF routing protocol outperforms HH-VBF protocol, naïve Flooding and RDBF in terms of energy efficiency, end-to-end delay and data delivery ratio.

1. Introduction

70% of the earth surface is covered with water. With the decrease of the terrestrial resource, human being pays more attention to the exploration of ocean resource. As we all know, the underwater adverse environment, especially the deep ocean region, is not suitable for human being because of the huge pressure and low visibility. Therefore, underwater acoustic sensor network (UASN) is widely used in coastline surveillance and protection, ocean disaster prevention, pollution monitoring, military defense, assisted navigation, marine aquatic environment monitoring, and resource exploration, etc. [1–3]. In underwater environment, radio, widely used as wireless transmission media in the terrestrial sensor network, cannot work well due to quick attenuation, resulting in short propagation distance. Acoustic signal is more suitable for the underwater transmission since it can transmit longer.

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However, underwater acoustic sensor network using acoustic signal as transmission media (UASN) poses grand challenges [4].

Firstly, the propagation speed of acoustic signal in underwater environment is approximately 1500 m/s [5], which is five orders of magnitude less than the radio frequency. In addition, it varies with the depth and sanity. The low propagation speed results in the long end-to-end delay. Therefore, the traditional terrestrial communication mechanism is not proper for UASNs.

Secondly, underwater channel is affected by many adverse factors, such as multi-path fading, noise, path loss and Doppler spread, which cause the high bit error rate.

Thirdly, due to the limited bandwidth of acoustic channel, it features low data rate. Currently, the available underwater bandwidth is approximately 40 km $\times$ kbps [1,3]. Therefore, the traditional information exchange communication fashion greatly affects the communication efficiency of UASNs.

Fourthly, underwater sensor nodes are usually mobile with the action of water current and other underwater activities. High mobility makes traditional routing mechanism not efficient since the stored routing information and network topology structure are not stable any longer when time passes.

In addition, underwater acoustic sensors are powered by batteries. Energy-conversation must be considered since it is difficult to replace or recharge after deploying sensor nodes in adverse underwater environment, especially in the deep ocean. Therefore, reducing energy consumption becomes one of the important factors in designing UASN.

Besides, deploying underwater acoustic sensors is costly as it needs the aid of ships due to their large size [6]. Due to high manufacturing cost, high design cost and the large monitored area, in general UASNs are sparsely deployed. The sparse deployment of UASN becomes one of the important factors during the design and implementation process.

Due to the above-mentioned constraints, the routing mechanism of the terrestrial Ad hoc sensor network cannot work well in underwater environments. Therefore, designing a reliable, energy-efficiency routing protocol as well as reducing the end-to-end delay as short as possible becomes one of the important research issues in UASN, especially sparse USAN in the deep ocean.

Motivated by the above considerations of the features of USANs, in this paper we propose a new scheme, adaptive hop by hop vector-based forwarding (called AHH-VBF) in underwater sparse acoustic sensor network of the deep ocean. AHH-VBF can adaptively adjust the forwarding range of packets and transmission power in cross-layer fashion. In this way, not only the energy consumption can be reduced efficiently, but also the reliability can be guaranteed. What is more, the end-to-end delay can be decreased by means of optimizing the holding time of packets.

The contributions that we have made in the paper are highlighted as follows. Firstly, we propose a novel and efficient transmission method, AHH-VBF, which can adaptively adjust the forwarding range hop by hop according to the neighbor node distribution. Secondly, in AHH-VBF, we optimize energy–efficiency by adaptively adjusting the transmission power with cross-layer approach. Thirdly, the holding time of packets is further optimized to reduce end-to-end propagation delay in AHH-VBF. What is more, two metrics are presented to evaluate network performance. Finally, our simulation results showed that the performance of AHH-VBF routing protocol is superior to HH-VBF in terms of reliability, energy-efficient and end-to-end delay.

The rest of this paper is organized as follows: in Section 2, we review the related works about routing protocols in this field. Section 3 defines network architecture and propagation model. AHH-VBF routing protocol is described in detail in Section 4. In Section 5, we make the theoretical analyses about energy consumption and end-to-end delay. Finally, we present the simulation results in Section 6, followed by our conclusions and future works in Section 7.

2. Related works

In this section, we first review the related works on routing protocols in USANs, and summarize their advantages, disadvantages and the existing problems. After that, we discuss some related works on AHH-VBF routing protocol.

The current existing routing protocols for terrestrial sensor network can be classified into proactive routing, reactive routing and location-based routing. However, the routing protocols designed for terrestrial sensor networks cannot be directly used in underwater acoustic sensor network due to the long propagation delay, high mobility, limited bandwidth, energy-constraint and high manufacture-cost and deployment cost. Because of energy constraint and the limited bandwidth, the proactive routing protocols which establish the routing table in advance [7], such as DSDV [8], are not suitable for the underwater acoustic sensor networks.

In underwater acoustic sensor network, routing protocols can be classified into three-dimension location- based, depth-based, location-free routing and reactive routing. Three-dimension location-based includes VBF, HHVBF, DFR, FBR and so on. Depth-based routing includes DBR, hydro cast, EEDBR and DBMR and so on. Location-free routing is classified into clustering routing and beacon-based routing.

In [9], Jornet et al. proposed Focused Bream Routing (FBR) to reduce the unnecessary flooding. In FBR protocol, prior to sending or forwarding packets, nodes gradually increase the forwarding range by adjusting the flooding angle and transmission power levels according to the pre-regulated angle gradient and power gradient. However, the nodes need to make many attempts to send RTS especially in the sparse network, which wastes a lot of energy and increases the end-to-end delay. In addition, the flooding angle has great influence on network performance.

In order to reduce the extra delay caused by RTS packets and CTS packets in FBR, the receiving range of data packets are directly adjusted by changing the flooding cone angle and the transmission power level step by step instead of