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A Comparative Study on Routing Strategies for Underwater Acoustic Wireless Sensor Network

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Abstract

The wireless sensor network (WSN) applications are one of the main reason for developing the Underwater Acoustic Sensor Networks (UW-ASNs). The delay-tolerant network (DTN) is a unique wireless network, which enables mobile nodes to communicate with each other where there is no continuous route between end nodes. It exhibits long and frequent propagation delay in transmission of data. The network suffers from various levels of link interruption depending on the operating conditions. One of the applications of DTN is Underwater Acoustic Network (UAN). The Underwater networks are formed by ocean-bottom sensor nodes which are connected via acoustic modem, autonomous underwater vehicles and a surface station which connects the onshore control center. Due to low bandwidth of acoustic channels and large propagation delays between the two nodes make routing in underwater network communication a very difficult task. The goal of this paper is to investigate the existing routing protocols of underwater communication and analyze the various routing objectives which are suitable for this particular application.

Keywords: Unmanned underwater vehicle, Autonomous underwater vehicle, Delay-tolerant network

1. Introduction

Underwater Acoustic Sensor Network (UW-ASN) consists of a variable number of ocean-bottom sensors, autonomous or unmanned underwater vehicles (AUVs or UUVs) which are sparsely deployed to perform oceanographic data collection and monitoring over a specified area. In underwater acoustic (UWA) network, the various instruments are established [4]. These instruments are attached with acoustic transceivers and then this system is connected to satellite via radio frequency link. The terrestrial application transmits the data packets through RF links whereas the data collected underwater network uses acoustic channels for transmission [5]. There is a broad range of applications for underwater acoustic sensor networks such as undersea exploration, monitoring the underwater environment etc. The network topology is frequently changed in offshore environment. Under such conditions, the communication path between source to destination pair can no longer. There are many researches are currently engaged in developing routing protocols for delay-tolerant wireless sensor network. The challenging characteristics of underwater communication make it difficult to design reliable and efficient routing algorithm.

2. Background

In this section, we address the various challenges of underwater acoustic sensor network and types of underwater communication network architecture.

A. Challenges of Underwater Acoustic Sensor Network

In the underwater network environment, sensor nodes and unmanned vehicles are communicate using acoustic waves. The acoustic channels in underwater communication exhibit drawbacks such as limited bandwidth, propagation delay is large and low transfer rate when compared to radio frequency (RF) terrestrial sensor network.

The major challenges in designing a routing protocol for underwater acoustic network are [2]:

- Propagation delay in underwater is much higher than in the terrestrial network due to radio frequency (RF) channels.
- The acoustic link quality is highly unpredictable.

- The available bandwidth is very limited.

- Loss of end-to-end path between two communicating nodes due to acoustic channels.

- Limited battery power of sensor nodes.

- Underwater sensors are prone to failure.

- If sensor nodes are not anchored, then the nodes are move away by generate the offshore current effect [7].

3. Underwater Acoustic Sensor Network Architecture

In general, there are two categories of underwater communication network architecture. One is based on the moving nature of the sensor nodes and the other is based on the spatial coverage [3]. The UASN architecture based on the moving capacity of the sensor nodes can be classified as stable, mobile or hybrid UASNs. The sensor nodes in the stationary UASN are attaching to ocean floor units. Such UASNs are mainly used to monitor certain areas such as harbor entrances. The underwater sensor nodes contains different features. The unpropelled sensor nodes in a UASN will float freely underwater. Examples of propelled devices are AUVs (Autonomous Underwater Vehicles) and UUVs (Unmanned Underwater Vehicles). Examples of such unpropelled equipments are gliders, floats, and drifters. In hybrid UASN architecture, both stationary and mobile nodes co-exist. The latter categorization is designed on spatial coverage property, namely 2D underwater sensor networks and 3D underwater sensor networks [1]. First, we describe the communication architecture of the 2D underwater sensor network.

A. Two-dimensional Underwater Sensor Network Architecture

The two-dimensional underwater sensor network comprises of underwater sensor nodes, which are inter connected with underwater sinks (UW-SINKs) via acoustic channels. The underwater sensor nodes are anchored by means of deep ocean anchors as shown in Fig. 1. There are two types of transceivers equipped with underwater sink mainly to forward the data. They are acoustic transceivers which are used by underwater sink namely horizontal and vertical transceivers. The horizontal transceiver is to connect every sensor with underwater sink. The vertical transceiver is to relay the data to offshore surface station. Each sensor relays the collected data to selected underwater sink which then relay it to surface sink.

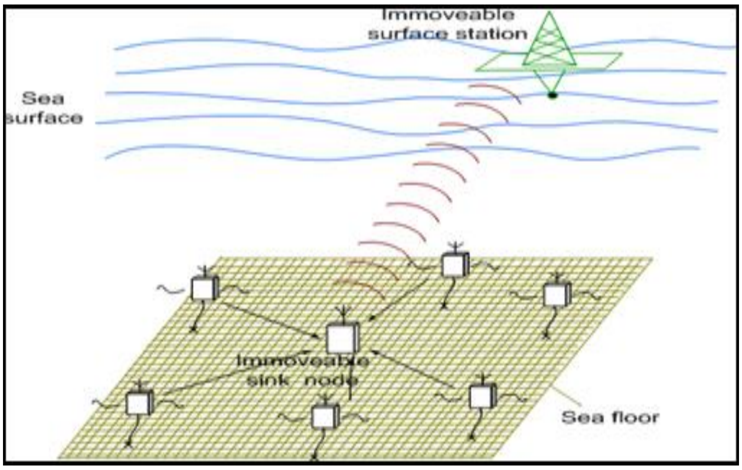

Fig. 1. Architecture of 2D underwater sensor network

B. Three-dimensional Underwater Sensor Network Architecture

In three-dimensional underwater sensor network architecture, the sensor nodes are fixed at bottom of the ocean as shown in Fig. 2. They may be floating at an arbitrary depth [3]. They are attached with floating buoys which is used to push the sensors towards the ocean surface. The depth is controlled by electronic engine that is residing at the sensor.

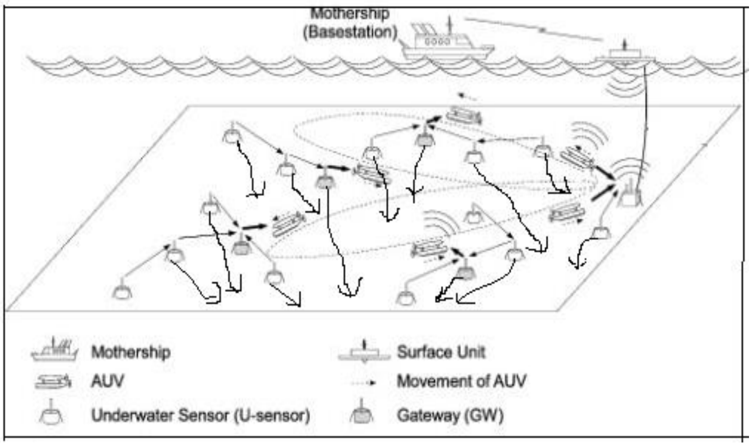

Fig. 2. Architecture of 3D underwater sensor network

4. Routing Strategies

The main objective of routing is to determine the shortest path from source (underwater sensor) to destination (usually the surface station). The routing objective is not only to determine the shortest path, but also to maximize the delivery ratio and minimize the delay in transmission. Routing in underwater communication is more difficult due to long propagation delay and low bandwidth present in a water medium.

The existing routing protocols for underwater sensor networks [1], can be categorized into six major types as listed in Table I.

A. Clustering Routing Protocol

This type of protocol uses cluster based approach in which a cluster head is elected among a group of underwater sensor nodes. In this section, it is necessary to describe two clustering protocols for underwater network.

- Minimum-Cost Clustering Protocol (MCCP): It is a cluster based protocol in which clusters are created by the following three criteria: residual energy of cluster head and its members, total energy needed by cluster members to transmit the data to the head node, cluster head location and offshore mobile sink [1].
- Distributed Underwater Clustering Scheme (DUCS): It is based on a distributed approach and doesn't need any location information [9]. This protocol has two phases. The initial phase or setup phase is the first phase in which clusters are constructed by selecting the cluster head and cluster members. The second phase is the steady phase in which data packets are transmitted.
- Location-based Clustering Algorithm for Data collection (LCAD): In LCAD, the whole network is divided into 3D grid and chose the head of cluster accordingly.

B. AUVs Assisted Routing Protocol

In AUVs Assisted Underwater Routing protocol, there are many UUVs (Underwater Unmanned Vehicles) which are used to provide enhanced connectivity with multiple underwater unmanned vehicles.

- Delay-tolerant Data Dolphin (DDD): It limits multi-hop communication, but the cost becomes a major issue. Due to the mobility of AUVs, it can be applied for a high data rate channel to transmit huge data. It achieves a high delivery ratio, low energy consumption [1]. The total number of transmission is minimized by using AUVs as relay nodes, but it will produce much cost.

Table I
Comparison of Different Routing Protocols for Underwater Sensor Network

SNo	Routing Protocol	Classification	Power Usage	Hop Count	Benefit	Drawback
1	MCCP	Clustering Based	Low	One	Prolong network life	Low delivery ratio
2	DUCS	Clustering Based	Low	Not mentioned	Localization is not needed	High end-to-end delay

3	LCAD	Clustering Based	Low	One	Low energy consumption	Network performance depends on grid structure
4	DDD	AUVs Assisted	Low	One	High delivery ratio,Low energy consumption	Huge cost
5	VBF	Geographic Based	Limited	Not mentioned	Reduces network traffic, Good packet delivery ratio	High communication overhead
6	HH-VBF	Geographic Based	Limited	Multi	High delivery ratio	Medium end-to-end delay
7	FBR	Geographic Based	Low	Multi	Reduces flooding	Not suitable for sparse environment
8	SBR-DLP	Geographic Based	Limited	Multi	Avoids flooding	High end-to-end delay
9	DBR	Geographic Based	Limited	Multi	Enhance network lifetime	No mechanism to suppress redundant data
10	PBR	Geographic Based	High	Multi	Limits co-channel interference, Low end-to-end delay	Not mentioned
11	H2-DAB	Epidemic Based	High	Multi	Good delivery ratio, No extra equipment cost	High end-to-end delay
12	AR	Epidemic Based	Limited	Not mentioned	Achieves good packet delivery	Average end-to-end delay is high
13	PURLP	Epidemic Based	Limited	Multi	Requires no localization, time synchronization and routing table	Delivery rate is based on ring radius
14	MPR	Epidemic Based	Limited	Multi	Good packet delivery ratio for dense network, Avoids collision	High energy consumption
15	RR TCBR	Special Routing	Not mentio ned	Not mentioned	Node depth can be adjusted by buoys	Cost to equip nodes with mechanical devices is high
16	HYBRID	Special Routing	Low	Not mentioned	Supports acoustic and radio communication, High delivery ratio	Cost is high

C. Geographic-Based Routing Protocol

The location information of sensor nodes can be used in this approach.

- Vector-Based Forwarding (VBF): Here every node knows its position already. Data's are communicating between source and sink using virtual routing pipe line. The data packet maintains the location of the source, the destination and the forwarder [8]. It also maintains a RANGE field which is used for mobility. The VBF protocol manages the changes in network topology and reduces network traffic [1]. But it increases the transmission overhead.
- Hop-by-Hop Vector Based Forwarding (HH-VBF): It is the successor of VBF protocol. In VBF, the data delivery is performed in a virtual routing pipe whose radius is assumed a certain threshold. VBF considers a single routing vector where as, HH-VBF considers the routing vector from each forwarder towards the destination. These are difference between HH-VBF and VBF. In these vector communication between a source to the destination by using virtual links.
- Focused Beam Routing (FBR): It is a feasible routing protocol suitable for both static and mobile underwater networks. In FBR, each node reading the location itself. So sensor node locations are stored in the base station. Here base station sends the destination location to the source node. Though it reduces unnecessary flooding, it is not suitable for dense environment.
- Sector-Based Routing with Destination Location Prediction (SBR-DLP): Here base station sends the node location to every sensor node and also send the preplanned routing path between source and destination. Hence, instead of finding an end-to-end path, data is forwarded to the destination, hop-by-hop to avoid flooding. In SBR-DLP, routing is performed in a sector based area [9]. The communication region is divided into many sectors. The nearest sector to the destination is selected to perform routing.
- Depth-Based Routing (DBR): This type of protocol requires the sensor node depth information in underwater environments. If a node wants to forward the data, it simply broadcasts it [8]. Upon receipt of the data, the neighboring node compares its depth with depth of the sender node. If the depth of the nodes is lesser then sender can receive these packets. Otherwise the remaining nodes are drop these packets. DBR handles network partitioning efficiently, but it does not produce a high delivery ratio in sparse regions. The disadvantage of VBR is broadcasting that increases the routing complexity.
- Pressure-Based Routing (PBR): It is similar to DBR. It is achieved by pressure level instead of depth for forward the packets, which is hydraulic pressure (HydroCast) anycast routing protocol. It limits the co-channel interference and does not require any localization process. Instead, it is performed after the data reaches the surface.

D. Epidemic Routing Protocol

- Hop-by-Hop Dynamic Addressing Based (H2-DAB): The data is forwarded towards the water surface. Here sensor nodes are deployed in two ways.

First one is some sensor nodes are floated in underwater environments and these sensor nodes having dynamic HopID. Some sensor nodes having static HopID. There are two types of addresses for floating and surface nodes. H2-DAB results in high delivery ratio. It does not need any special hardware and there is no extra equipment cost. Despite of good delivery ratio, it causes high end-to-end delay.

- Adaptive Routing (AR): Adaptive routing protocol mainly exploits the data redundancy. The routing is accomplish adaptively based on the requirement of the applications. It achieves good delivery and provides less energy consumption. The spherical shape region called forwarding region with predetermined diameter is used in adaptive routing. Based on the importance of the packets, they are forwarded to the nodes that are in the forwarding region. The forwarding region increases when number of packets are routed into it.
- Path Unaware Layered Routing Protocol (PURLP): PURLP algorithm contains two phases [7]. The first phase is a layering phase. Here concentric spheres are presented around a sink node. The radius of the sphere is determined based on the data delivery latency. The second phase is communication phase in which the intermediate relay nodes are chosen. PURLP determines route on the fly from source to sink through chosen relay nodes. The algorithm results in better delivery rate and minimum delay.
- Low Propagation Delay MultiPath Routing (MPR): It constructs a path between source to the destination. The path contains a number of multi-subpaths and each sub-path is defined as a path from source to its two-hop neighbor through an intermediate relay node. The main advantage of this routing algorithm is to avoid collision. It requires many matrix operations to eliminate collision that results in high energy consumption.

E. Special Routing Protocol

The special routing protocols such as Resilient Routing Algorithm and Temporary Cluster Based Routing (TCBR), the underwater nodes fix their position via anchors and adjust their depth through buoys [1].

- A hybrid underwater protocol: This protocol supports both radio and acoustic communication. It uses an acoustic communication when the nodes are underwater, and radio communication when they are on the surface. It consumes less energy and achieves a high delivery ratio. However cost is increased to equip these mechanical devices (buoys, anchors, ropes) in all the sensors.

F. Mobicast Routing Protocol

Mobicast is a spatiotemporal multicast. This protocol is designed to provide a spatiotemporal solution to deliver the wake up messages to the correct place at the correct time [6]. In this protocol reduces the energy consumption in 3D underwater sensor networks (USN). This is achieved by creating the Zone of reference regions for collecting the data’s in underwater environment using Autonomous Underwater Vehicle(AUV). The AUV travels along a path which is defined by the user to fetch the sensed data from a sensor node. It provides an efficient data collection and an energy saving routing protocol for the USN.

5. Conclusion

In this paper, we presented an overview of underwater acoustic sensor network. We described the challenges posed by underwater channel with reference to the routing. In this paper, we focused mainly on the various routing strategies for underwater acoustic sensor network and the classification of underwater communication network architecture.

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