CLUSMOB Protocol Based on Clusters for Mobile Underwater Networks

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***Abstract*—The need for underwater wireless sensor networks having mobile sensor nodes has been there for a long time in form of underwater warfare or explorations by Autonomous Unmanned Vehicles (AUVs) or Remote Unmanned Vehicles (ROVs). The constant and random movement of the sensor nodes makes it difficult to select the next forwarding node because it is quite obvious that nodes can go away from the gateway node due to movement. This results in increased end-to-end delay and inefficient energy consumption by sensor node. There are very few protocols for ad hoc mobile underwater wireless sensor networks (AMUWSN). Thus, we present an ad hoc Mobile routing protocol for AMUWSN. Designing a protocol for AMUWSN is quite challenging for the reason of its continuous random movement of the sensor nodes. These sensor nodes may need to communicate each other and with the gateway (GW). The proposed protocol is a self-organizing routing technique based on clusters that uses received signal strength (RSS) for distance estimation.**

Keywords—underwater; UWSN; location-free; routing protocol; self-organized; self-configured; wireless networks; AUVs, ROVs

I. Introduction

The routing protocols for underwater wireless sensor networks (UWSN) have different issues than those used for terrestrial wireless sensor networks (TWSN) because of acoustic transmission medium. There are many routing protocols for UWSNs assuming that the nodes are either fixed or anchored to the bottom of the sea. These UWSNs are used to sense data in a predefined area like environmental monitoring of plume or surveillance of marine structures. However, UWSNs are also used for applications where the sensor nodes are mobiles. Ad hoc mobile underwater wireless sensor networks (AMUWSNs) have applications like mobile marine surveillance and marine explorations. The mobile nodes may be the divers, Autonomous Unmanned Vehicles (AUV) or Remote Unmanned Vehicles (ROV). The random movement of the mobile nodes make necessary they need to communicate each other, either to forward each other's data or exchange the information, such as the divers need to communicate each other. The mobile nodes may also need to send the data to some station on the sea surface or on shore data gathering station. The continuous movement of the nodes makes the communication and routing of the data packets a very challenging task. Any of the existing UWSN routing protocols cannot work for AMUWSN, because they are designed for fixed topology networks. A classification for the routing protocols may divided them into proactives and reactives. However, due to the continuous random movement of the nodes, the routing protocol must be reactive, i.e. In reactive routing, route discovery is used to find the route when sending the data packets. The route remains till the destination is within reach. The decision of routing is based on the current state of the network and mainly the topology in this case. A typical AMUWSN is shown in the Figure 1.

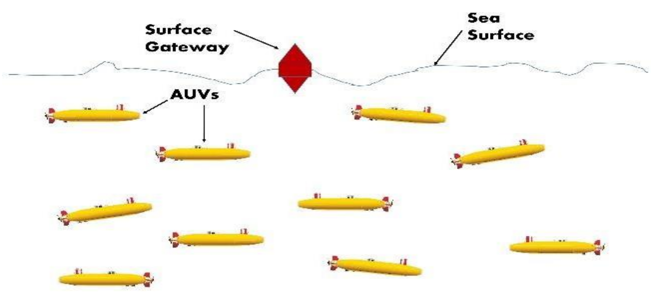

Figure 1. Scenario of an AMUWSN consisting of quasi-randomly moving AUVs

We have designed a routing protocol for AMUWSN to send the packets from the mobile nodes to the gateway at the sea surface. The protocol is cluster based to conserve the energy of the nodes.

II. Related Work

The Distributed Underwater Clustering Scheme (DUCS) [1] is a cluster based self-organizing protocol. The nodes form the clusters by one of the nodes assume the role of cluster head. Cluster Heads (CH) nodes aggregate data received from single-hop cluster nodes and send it to the sink using multihop routing via other cluster heads. It is assumed that within a cluster the nodes are close to each other and may send the correlated data to the CH node. Therefore, a CH node filters out the redundant data from the cluster nodes and sends only non-redundant data to the sink. The filtering of redundant data helps to save the energy of the CH node. A CH node is chosen based on the maximum battery capacity and the current battery level. The nodes select the nearest CH node which requires them to measure their distance with the CH nodes. This distance is calculated by the Time of Arrival (ToA) technique. The CH node also controls the communication among the cluster nodes and with the other CH nodes. The CH node assign the time slot to each cluster node based on Time Division Multiple Access (TDMA). The time slots to the nodes are assigned using Code Division Multiple Access (CDMA) technique. CDMA is also used by the clusters to send the data to the sink node. Nodes in a cluster keep switching the role of CH among themselves to save energy.

HAMA [2] proposes an AUV based protocol which uses multiple AUVs to provide data collection which is highly available. Usually, the trajectory of the AUV based protocols is fixed which causes rapid energy depletion of the nodes near the trajectory. It is also possible that the AUV goes down because of some malfunction. HAMA uses multiple AUVs, changing trajectories and spreading the AUV failure intimation throughout the network to address these issues. The nodes determine their location to use it with AUV's trajectory path to determine whether they have adequate time to send out packets to the moving AUV. However, it is not described that how the nodes will determine their location. The nodes can predict the location of the AUVs because of their predefined path.

P-AUV [3] is a routing and a medium access protocol. The sensor nodes are deployed as AUVs by a ship or a submarine. It is assumed that the AUVs are aware of their position at the time of deployment. AUVs track and update their position and mission path using two factors that are Inertial Measurement Unit (IMU) and Doppler Velocity Log (DVL). IMU is an electronic device, consists of accelerometer and gyroscope, measures axial acceleration and rate of rotation. DVL is used to estimate velocity of an object relative to the sea bottom. DVL transmits acoustic beams in three different directions. Due to the movement of the object, the apparent shift in the frequency is used to measure the velocity of the object.

Opportunistic Power Controlled Routing (OPCR) [4] is an opportunistic protocol for Internet of Things (IoTs). It is based on link quality, nodes density, distance, packet advancement and energy consumption. Opportunistic routing and variable transmission power control system work together to lessen the energy waste. The concept of OPCR is very simple. The forwarding node reduces the transmission power where the node has high neighborhood density if the link quality between the neighbor nodes and the forwarding nodes is acceptable to deliver the data reliably. Hence, a transmitter node ought to have the information of the neighboring nodes. A beacon packet is used to discover the neighbor nodes. To determine which neighbor nodes can forward the packet towards the gateways, the location of the nodes need to be known. OPCR does not define any localization method itself and recommends using any localization protocol proposed for UWSN.

SOFRP [5] is a location free, self-organizing, cross-layered protocol for radial topology. It is proactive protocol to minimize the routing delay. Before data transmission begins, the routing path for all the nodes to send data to the gateway is formed. The routing paths formation is initiated by the gateway. The nodes find their neighbors and the network topology by using the messages only. The messages are sent at randomly selected timeslots to avoid collision. The route formation happens in such a way that the nodes which are in a straight line called as string forward the packets. To make the protocol robust the routing path can be changed if a node goes down. The nodes forward the data packets use string identification (ID) in the header of each packet. Since the forwarding node does not need to match the source ID or change the destination ID, the packet forwarding quite fast in SOFRP.

Self-Organized Proactive Routing Protocol (SPRINT) [6] is a self-organized, proactive, cross-layered protocol. It is aimed to reach the high data throughput and save the node's energy. SPRINT selects the next forwarding nodes based on the distance between source and the relays, number of relays used to traverse the packet from the source node to the gateway and the number of neighbors of each relay. The distance is measured by received signal strength (RSS) to make the protocol location free.

EEPFSFDM-UWSN [7] (Energy-Efficient Packet Forwarding Scheme Based on Fuzzy Decision Making in UWSNs uses fuzzy logic to select the relay node. The selection of relay node is dependent on input parameters that are i) Number of hops (NH), ii) Number of neighbors (NN) and iii) Distance based on RSSI (Received Signal Strength Indicator). The proposed protocol chooses the relay node based on linguistic variable and uses triangular fuzzy membership function. The proposed protocol saves the node's energy by making decision to chooses the best relay node based on distance from the sink, number of neighbors and number of hops to reach the gateway.

In [8] AEDG (AUV aided efficient data-gathering) routing protocol is used for reliable data delivery in underwater sensor networks. To extend network lifetime, AEDG collects data from gateways using AUV, which uses the shortest path tree algorithm to reduce network energy consumption. AEDG uses the limitation of associated nodes with the gateway to prevent the gateway from overloading to minimize energy consumption.

The work in [9] proposes the MEES scheme (mobile energy efficient square routing protocol) which is used to balance energy utilization. To cover maximum field of the network they introduced two mobile sinks moving linearly in predefined and clockwise direction. These mobile sinks in this case are deployed away from each other. This mechanism is based on transmission range and those nodes are allowed to send data which are in the transmission range (TR). Periodic mobility of the nodes balance the energy consumption of the network. The scheme increases both the throughput and lifetime of the network.

Authors in [10] propose a new scheme named AEERP (AUV aided energy efficient routing protocol). This scheme is based on the adaptive selection of the gateway which balances energy by enhancing lifetime of the network. Gateway nodes are chosen based on received signal strength indicator (RSSI) value of a hello packet received for the AUV. In terms of energy cost and data delivery ratio, this scheme outperforms the TSP travel salesman problem.

Author in [11] proposes a novel technique where two mobile sinks are used which collects the sensed data packets in efficient way. A new factor is introduced by the author that measures usage of mobile sink in terms of collecting data packets. The deployment of mobile sinks are done by dividing the sensor field into vertically named as left sided region and right sided and further are equally divided into 5 regions, and mid-points of these regions named as left-5 regions and Right-5 regions. The total of three mobile sinks are employed wherein one is static and other two are mobile. The mobile sinks are employed to gather the data from the sensor field whereas the static sink (GW) is placed at top mid of the sensor field. By using mobile sinks in efficient and optimum way leads to an improved throughput and enhanced network lifetime in the routing protocol.

Authors in [12] propose 3D-SM protocol. In this work, both the courier nodes (CNs) and Mobile Sink (MS) which are also known as AUV, are mobile which increases network lifetime and minimizes delay. Due to MS and CNs stop off at certain stops for data gathering and later the CNs nodes forward the received data to the MS for further transmission.

In [13] the proposed protocol establishes an AUV assisted energy efficient clustering in underwater wireless sensor networks, and it works on the mechanism of sleep wake cycle of the sensor nodes. In this protocol, AUV includes creation, nomination of CH node and creation of sleep-wake cycle which releases the burden of underwater sensor networks. In other words, it performs load balancing in the network. The proposed protocol provide stability to the network and data can be delivered reliably for extended timespan.

III. Proposed Protocol for UWSNs

Our protocol is designed for ad hoc mobile UWSNs. The goal of the protocol is to deliver the packets with minimum delay and with minimum packet loss which will enhance node energy. The mobile nodes may be AUVs or ROVs, which are used for surveillance and environmental monitoring. The direction of the mobile nodes is usually random, but they are in constant movement. Due to this fact, the selection of next forwarding nodes becomes very challenging. The next forwarding nodes cannot be selected in advance, so when a packet is to be forwarded the process for selecting the next node starts. It is quite possible that a node selected for the packet forwarding moves away by the time packets is forwarded. In UWSN where acoustic waves are used this issue become worsens owing to long propagation delays of the acoustic waves in the water.

The proposed routing protocol is cluster based as shown in Fig 2. The gateway is stationary while the sensor nodes are mobile. The red triangle shows the stationary GW, the yellow diamonds show the mobile Cluster Heads nodes (CHs), the blue dots show Ordinary Sensor Nodes (OSNs) and the green circles show the clusters regions. A CH node will work as a sensor node as well as a cluster head. A CH node has long transmission range and have more energy available than the OSNs.

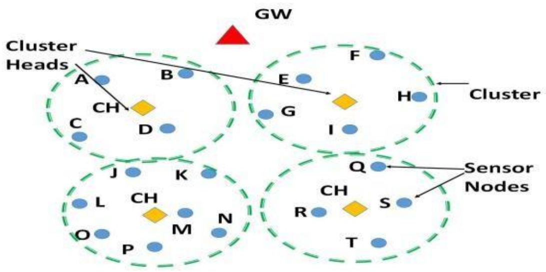

Figure 2. Clusters in an AUV network

The GW will initiate the routing path formation by broadcasting Beacon (BCN) packets periodically. The BCN packets are used to find the CHs. The CHs which will receive the BCN packet will form a path with the GW and will be responsible to forward the data packets of their own cluster nodes and the other CHs to the GW. To distinguish the clusters in the neighbor of GW are called Packet Forwarder Cluster Heads (PFCHs). The PFCHs will announce their role of packet forwarder (PF) to other CHs by broadcasting the BCN packet. The CHs which will receive the BCN packet from the PFCH will rebroadcast the BCN. This will persist until all the CHs in the network have received the BCN packet. A CH will select the next forwarding CH when the data is to be forwarded. The selection will be based on number of hops and residual energy.

A cluster will be formed by the OSNs. An OSN will select the nearest CH by the BCN packets received from the CHs. An OSN will compare its distance from the CHs and will select the CH which is closest to it. The process of CH selection by OSNs will occur every time the BCN packet is broadcast by the CHs. The rate of repeated broadcast of BCN packet from the gateway, PFCH and CHs will depend on the speed of the moving nodes. The role of PFCH will keep rotating among the CHs because the CHs are also mobile.

IV. Simulation and Results

We have simulated the proposed protocol on MATLAB for the packet drop ratio (PDR). The parameters for the simulation are given in Table 1.

Table 1. Simulation Parameters

S.No.	Parameter	Value	Unit
1	Sound Speed	1500	m/s
2	Data rate	5000	bps
3	OSN Transmission Range	500	m
4	CH Transmission Range	1000	m
5	Network Size	10 x 10	km
6	Depth	4	km
7	Number of OSNs	20	each
8	Packet Header Size	66	bits

The proposed protocol was analyzed for the packet drop ratio at the different number of cluster heads. The number of CHs varies from 2 to 10 whereas the number of OSNs remains constant. The PDR is the average of 50 runs for each number of CHs. The simulated result of the PDR is shown in Fig 3. The results show that the PDR decreases as the number of CHs increases. This result is as per expectation because as the number of CHs increases the chances of delivering the data to the sink also increase.

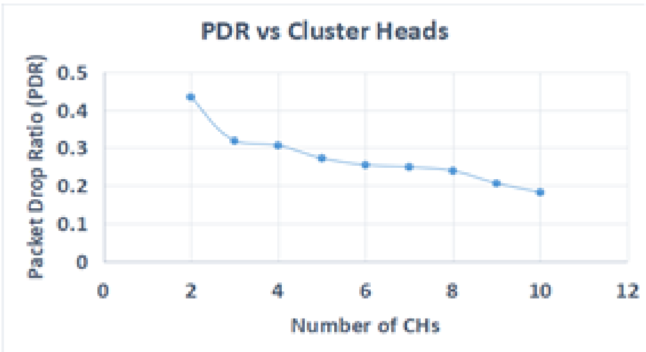

Figure 3. Packet Drop Ratio vs Number of CHs

V. CONCLUSION

Reactive routing protocol for mobile underwater sensors is proposed in this paper. The movement of the sensor nodes is steady and random. The mobile sensor nodes may be used to monitor the environment or for the marine surveillance. The purpose of the protocol is to establish the routing path between the moving nodes to send the data to gateway node with minimum end-to-end (E2E) delay and due to minimum E2E delay the energy consumption will also be minimized. The network is divided into clusters to reduce hop count. The formation of forwarding path between the CHs is initiated by the GW by broadcasting a BCN packet. The BCN packet traverses through all the network to get all CHs connected. The clusters are formed by OSNs selecting the CH based on the distance. The distance between a CH and OSN is computed using RSS by an OSN. In future we will also simulate the proposed protocol for throughput and end to end delay and develop an analytical model.

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