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Clustered Fair Data Transmission in Energy Efficient UWSNs

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Abstract: In Underwater Wireless Sensor Networks (UWSNs) energy, throughput are wide are of interest. These sensor networks make it possible in real time monitoring of the underwater environment. Major challenges that ar4e faced in such environment are low battery power, high bit error rates, low bandwidth availability etc. This paper mainly examines these challenges and possible solutions to overcome the problem by using a cluster based fair data transmission. Our work mainly focuses the formation of cluster that is supported by a metric known as Time – Distance – Ratio (TDR) and recharging the Cluster Heads by Autonomous Vehicles (AUVs). Finally, by using this strategy we prove that the energy used by sensor networks is lesser than other algorithms.

Keywords: Underwater Sensor Networks, Clustering, Energy Efficient, Autonomous Vehicles, Time-Distance-Ratio

I. INTRODUCTION

An underwater network is typically consists of self governing and individual sensor nodes that may by connected in a wireless or wired medium. It performs data collection operations as well as store and forwarding operations to route the data that has been collected to a central node. Underwater Wireless Sensor Networks (UWSN) has different features when compared to terrestrial wireless sensor networks. Some of the features we can consider are limited bandwidth capacity, Hardware Cost, Deployment Method, Data Correlation, Power Consumption, Synchronization, limited battery power, low throughput and high propagation delays. These underwater networks are scalable, ambulant and capable of self-organization[1].

While sensor-net systems are beginning to be fielded in applications today on the ground, underwater operations remain quite limited by comparison. Remotely controlled submersibles are often employed, but as large, active and managed devices, their deployment is inherently temporary[3]. Some wide-area data collect efforts have been undertaken, but at quite coarse granularities (hundreds of sensors to cover the globe) . Even when regional approaches are considered, they are often wired. From observation, nodes without any self-propelling capability can move with ocean current and wind at the rate of 0.83- 1.67m/s and existing Autonomous Underwater Vehicles (AUV) typically move at a rate of up to 2.9m/s[6].
The main challenges of deploying such a network are the cost, the computational power, the memory, the communication range and most of all the limited battery resources of each individual sensor node. As the life time of any individual sensor in the UWSN is limited, the number of sensor nodes that stop working due to the power loss increases with a lengthened deployment time, therefore the coverage area of WSN will shrink.

It is obvious that the issue of limited battery resources is particularly important and it is a challenge for researchers to obtain long operating time without sacrificing system performance. Therefore new, energy efficient protocols must be developed for all of the UWSN nodes' functions.

A. Types of Underwater Sensor Networks

- Fixed Sensor Nodes - Each node in the network are well adhered or fixed to the seafloor.
- Partial Migrant/Suspended Sensor Nodes – The drift/beacon that are set up by the ships hooks up the sensor nodes. These nodes are transiently utilized. They are hooked up for a period of time [7]. They are removed when the task is completed or when power goes down in order to recharge them.
- Ambulant Sensor Nodes – These Sensors are latched onto to AUVs, drifters, floaters [8]. Mobility is the main factor that is very much useful to increase the coverage of the sensor by using only limited/minimum implements. It also poses problems in perpetuating a well linked network[2]. But also faces challenges in the area of sensor node localization. For such communications, requirement of energy is enormous.

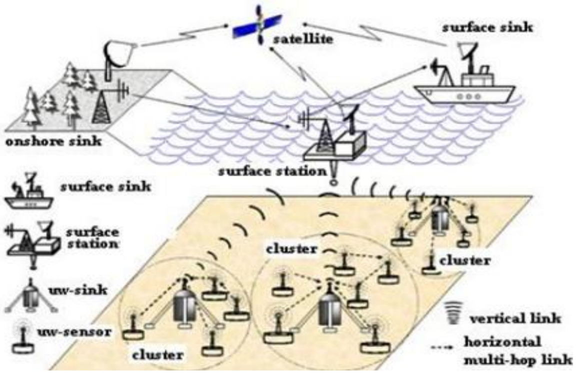

Fig. 1. A View of UWSN Environment

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B. Applications of Underwater Sensor Networks

- Seismic-Tracking – One of the advantageous application of underwater sensor are seismic-tracking/surveillance for withdrawal of oil/lubricant from subaqueous/marine areas [9]. "4 – D seismic" is widely utilized in determining the performance. It is also useful in the process of motivation intervention.

- Underwater cyborg - This supports groups of underwater autonomous cyborg which are also known as robots that can eventually sense, collect and transmit data such as chemical leakage or biological phantasm like phytoplankton flocking and also equipment managing [10].

C. Challenges of Underwater Sensor Networks

There are several challenges [11] faced in the underwater environments which are as follows:

- Gathering/collection of data reliably
- Synchronization of the clock time of sensor nodes
- Management of energy in order to secure lifetime of the network[4]
- Localization and security issues with respect to the nodes and their communication in the network
- Available communication link/bandwidth is limited due to the lack of fair channel sharing mechanisms [12].
- Sensor nodes may malfunction or fail due corrosions and other factors of underwater environment.

II. RELATED WORK

A. Location based Clustering Algorithm for Data Gathering (LCAD)

The transmission of data between sender and receiver sensor nodes depends upon the distance between them which in turn relies on the energy consumption. Due to the large number of data packets, it can lead to draining off the sensor node's energy. In Cluster based architecture for a three dimensional underwater sensor network where the sensor nodes are deployed at fixed relative depth from each other. All the sensor nodes are organized at their respective positions with the help of respective cluster heads, where the cluster heads are interlinked with each other by horizontal acoustic links, with a length restricted to a maximum of 500m for an effective communication proved in [15]. For a range of more than 500m, the use of autonomous underwater vehicle is practiced.

Phases of Communication:

Initial Setting Up Phase – Selection of cluster head among the ordinary sensor nodes takes place. This process is supported by an efficient and reliable algorithm.

Data Aggregation Phase – After the formation of clusters, the nodes initiate sensing mode. These sensed data are forwarded to the respective cluster head. Once the data has been received by the cluster head, it aggregated all the data to form a data packet with less number of chunks in order to ensure the highest data packet delivery ratio

Transmission Phase – Once the data has been aggregated it is further transmitted / collected by the autonomous vehicles. Autonomous underwater vehicles collect data packets from the cluster heads rather than every single sensor node in the network. These vehicles transfer the data to the sink/destination.

Cluster heads possess more memory and energy as compared to the member nodes as more memory and energy is consumed by the cluster heads as compared to the member nodes and retrospect, it makes the sensor network not only more reliable, but also balance the load in the network. It has formed a grid structure just like a cellular network, where the cluster head is located at the center, which helps it in communicating efficiently with the respective member nodes. Therefore, for the most optimal results, they supported a compact deployment of sensor nodes at the lower level of the structure and more dispersed at the higher level of the structure.

In accordance to the simulation results, the work has proved itself to be effective in terms of network lifetime. Though, location based clustering algorithm for data gathering has numerous advantages over other similar proposed network protocols, it has serious performance issues as well, especially that it depends completely on a grid structure, which is highly efficient when it comes to the terrestrial environment but is not feasible in underwater environments as node mobility is the prime concern as in case of the underwater sensor network. In underwater sensor networks, the nodes can move with the ocean current and can leave the network. Therefore, it could be possible that the nodes enter the neighbor grid or leave different grids frequently resulting in communication loss.

B. Distributed Minimum-Cost Clustering Protocol (MCCP)

The nature of cluster formation in terrestrial sensor network is not feasible with respect to the underwater sensor networks[5]. Thus the protocols proposed for cluster formation in the terrestrial sensor network do not hold the same reliability and efficiency in underwater sensor network due the challenges faced in underwater environment are more complicated than terrestrial networks. Distributed Minimum-Cost Clustering Protocol (MCCP) uses a cluster based approach in order to improve energy efficiency and prolong the network life. It consists of three parameters : residual energy and relative location of cluster head and sink in this approach, every node construct its neighbor set and their respective cost is calculated. Further, the average cost is computed and the minimum cost is selected as cluster head[13]. Cluster Head (CH) broadcasts an INVITE message to all the other cluster nodes to become its cluster's member, otherwise it sends a JOIN message to the specific cluster head.

Although, MCCP is an efficient centralized algorithm for data aggregation as it eschews the formation of hot spots

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near the underwater sink.Also, it has the ability to rebalance the traffic by clustering the sensor nodes time to time. But it has a few drawbacks as well, such as it does not support multi-hop routing. It has the ability to re-cluster the network, but re-clustering the network can take months, due to which it could be possible that the nodes can leave and enter different clusters as the underwater sensor network is assumed to be mobile.

C. Distributed Underwater Clustering Scheme (DUCS)
In underwater sensor network, sensor nodes have limited power and battery so it is not feasible to recharge or replace the nodes. Keeping this issue into concern, Domingo and Prior et al. [16], 2007 proposed a clustering scheme which supports the node mobility and energy degradation issue, and named it as distributed underwater clustering scheme (DUCS), an adaptive self-organizing protocol where the nodes organize themselves into clusters and a cluster head is selected from each cluster. The cluster head agglomerates the data sent by the respective cluster members as shown in Figurer.

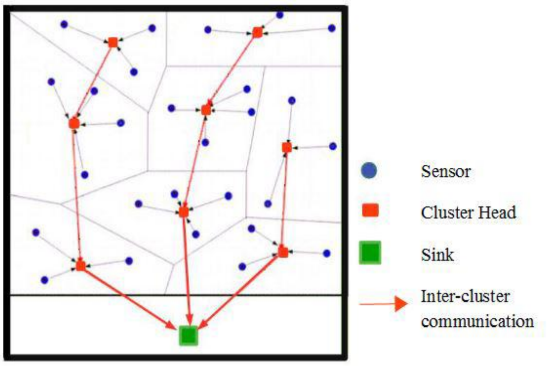

Fig. 1. Network using DUCS

Data transfer between the member nodes and the cluster head takes place via a single hop. After that, the cluster head performs data aggregation on the received data and forward the data to the sink via multi-hop routing with the help of remaining cluster heads, the redundancy of data is minimized and the energy is saved[5]. Cluster heads are responsible for both inter-cluster communication as well as intra-cluster communication.

Cluster heads are selected through a randomized rotation among different nodes in order to avoid draining of the battery from a particular node. DUCS works in two rounds: (i)Set-up Phase: A network is formed by dividing the network into a number of clusters and cluster heads are formed using the respective cluster formation algorithm; (ii) Network operation phase: Transfer of the packets is completed in this phase. DUCS has turned out to be an efficient clustering and aggregation scheme as simulation results have shown increased throughput and also achieves a high packet delivery ratio. Although this scheme is efficient, but it has some serious issues like node mobility is not considered so node movements due to ocean currents can affect the structure of clusters that it reduces the network overhead[18]. Also, the cluster head is bound to send the data to another cluster head only. In that case, ocean currents can move two cluster head nodes far away such that, while data transfer between the two cluster head, there are a few non-cluster head nodes available between them.

D. Hydro Cast
Uichin et al. [14] proposed a hydraulic pressure based anycast routing protocol called HydroCast in order to overcome the limitations of geographic routing. Since geographical routing in underwater environment is quite complex and consumes more cost, there was an urge to solve routing problems. Thus the HydroCast algorithm analyzes the pressure levels by measuring and comparing the levels at different geographical locations.

It uses the measured pressure levels to find the routes for forwarding packets from source to the sink/surface buoys. It is stateless and completes its task without requiring expensive distributed localization. Hydrocast nodes are designed with a low cost pressure sensor to measure their own depth locally.

Multiple mobile sinks are also deployed on water surface, which move with water flow. With regard to discovering a positive progress area toward to the sink, this protocol exploits only the information that is estimated by measuring the pressure of water in different depths.

This algorithm mainly comprises of two stages:
The forward selection set and the routing recovery mode – In the first stage an opportunistic forwarding mechanism is used to select a subset (cluster) of neighbouring nodes with higher progress toward to the sink as the next hop candidates. The neighbouring nodes that receive a packet will access their priority according to their distance to the destination; the closer to the destination the higher priority[19].

In this subset a node will forward the packet only when all nodes with higher priority progress to the destination fail to send it. This process is scheduled with the use of a back-off timer which is set up proportional to the destination's distance. All the other sensors with lower priorities will suppress their transmissions upon receiving the transmission (data or ACK packet) of a higher priority node.

By this way the possibility of collisions and redundant transmissions is minimized. In the second stage, a local maximum recovery mechanism is introduced in order to deal with the communication void. A node is considered as a local maximum node if there are no neighbours with lower pressure levels[17]. To overcome this problem it enables a void handling mechanism. According to this, each local maximum node finds and stores a recovery path to a node whose depth is lower than itself and transmits the data packet to this node.

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III.PROPOSED SYSTEM

Due to the challenges such as mobility, low lifetime of nodes, propagation delay etc., we propose an approach of creating an Underwater environment in which the sensor nodes form cluster using more reliable algorithm CLU-TDR (Cluster Based Time Distance Ratio) and in order to increase the lifetime of the network we use an autonomous vehicle for charging the target node ie the cluster head.

We construct a network consisting of nodes that are initially synchronized before they are set to transmit. Once these nodes are synchronized to the beacon/sink nodes, they are all set to transmit based on a unique metrics. Thus synchronization overcomes attacks such as delay attack, replay attacks etc. Along with such synchronization we also enforce the fair channel/bandwidth allocation among the nodes. For this purpose, we utilize a metric named as Time Distance Metrics [20]. Usually, propagation delay in terrestrial sensor network depends upon the propagation time. But in Underwater Wireless Sensor Networks, the propagation delays not only depend upon the propagation time but also on the propagation distance. Distance among origin/source-destination/sink/beacon will be major factor in order to determine the delay as well as to determine whether the sink can be reached or not. If the sink is not reachable, then it is of no use in transmitting the data. Thus the energy to be spent to transmit the data directly to such a node can be avoided or reduced.

Time Distance Metrics can be defined as the ratio among end–to–end delay and the transmission-distance of data/packet in the network. Consider the end–to–end delay of a data/packet as Td which is clock-time/duration that have crossed/completed, clock-time T' required for transfer/transport.

$$T_d = t - t_0 \quad \ldots\ldots\ldots\ldots \quad (4.1)$$

$$T' = (L' + L_{i+1})/V \quad \ldots\ldots\ldots\ldots \quad (4.2)$$

Here "t"-is generation-time with respect to data/packet, t0-is present/current clock-time, L' Euclidean Distance between node and the sink, Li+1-distance between ith node and next hope j^{th} node. Entire transmission of a packet can be given as $L_1+L_2+L_3+\ldots+L_i+L_{i+1}+L'$. Therefore Time Distance Metrics is:

$$M = (T' + T_d)/L_i \quad \ldots\ldots\ldots\ldots \quad (4.3)$$

The concept of Time Distance Metrics is not only used for reducing delay but also to provide a fair share of the bandwidth among the cluster heads that intend to transmit at the same time.

The system consists of three phases:

i) Configuration Phase: In this phase all the sensor nodes try to form the cluster. This process is supported by calculating a metric Time – Distance – Ratio (TDR). Each node calculated TDR with respect to the sink. The node with lowest TDR, highest memory and energy will be chosen as Cluster Head (CH). Rest of the node is considered as ordinary nodes.

ii) Clustering Phase: Once the Cluster Head has been chosen, the other ordinary nodes participate in the process of formation of cluster member (CM). Each node with relatively lower distance and TDR with respect to the closest cluster head will be assigned as Cluster Member (CM) to the cluster of that Cluster Head (CH).

iii) Transmission Phase: After the formation of cluster, each cluster member start sensing the data and the member with highest TDR will be given priority to transmit the data to its CH. Other members will goto Sleep State until their turn comes. Each Cluster Head will collect the data only from their respective Cluster Members and use the strategy of aggregation of data. This aggregation reduces the need for frequent transmission as well as uses less energy for transmission. Once the data packets are prepared to transfer, the Cluster Heads (CH) will transmit the packets to its nearest CH or if the sink is closer to the CH, it is directly transmitted to the sink.

iv) Charging Phase: This phase is very crucial because it improves the lifetime of the network. Here, we use an Autonomous Vehicle (AUV) to perform the process of charging only the Cluster Head. AUV periodically locates the CH and approaches the CH for charging.

ADVANTAGES:

i) More reliable
ii) Efficient
iii) Consumes less energy
iv) Robust

IV. CONCLUSION AND FUTURE WORK

We have proposed CLUS-TDR, a cluster based approach that ensures the energy efficiency in the underwater sensor networks. The configuration phase ensures that the cluster is formed accurately.

Once the cluster is formed, the transmission is performed in a fair manner by using Time – Distance – Ratio (TDR). Our system focuses on the increasing the life span of the network by using the AUVs for dynamically charging the Cluster Heads and the cluster member goes to sleeping state when they have nothing to send.

This assures that the network energy consumption is reduced and becomes more reliable. In future, we investigate this approach by using various clustering algorithms. Moreover, we will perform the analysis of the adaptability of our strategy and evaluate its performance through real ocean experiments.

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BIOGRAPHY

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