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Energy Efficient Routing Protocols for Underwater Sensor Networks-A Survey

Nithya Joy*, *Biju Paul*
Rajagiri School of Engineering and Technology
Cochin, India

Abstract— Underwater acoustic networks in a rapidly growing area of research as it finds different applications for monitoring and collecting data for environmental studies and military surveillance. The need for creating a new set of protocols optimized acoustic communication arises from the major differences in the underwater acoustic communication and terrestrial radio communication. Energy efficiency plays an important role in underwater acoustic communication as underwater sensor nodes are powered by batteries which are difficult to replace or charge on the node is deployed. This paper surveys the recent routing techniques that focus on energy efficiency. Each protocol is discussed in detail and the advantages and disadvantages are identified. The paper includes new research directions also.

Keywords— UWSN, Acoustic channels, Wireless Sensor Networks,Energy efficiency,Underwater communication

I. INTRODUCTION

Sensor networks are the result of continuous development in low power micro-electronics and sensors. Network consists of a set of tiny nodes or sensors which collect process analyze and simulate data. Each node is capable of wireless communication and transmitting and transmits data. The nodes are again classified into sensing nodes and aggregate nodes. The data sensed by the sensing nodes are aggregated by the aggregate node which is also known as the sink or the base station node. Sensor networks faces many challenges in common without considering the environment in which it is deployed such as the topology of the sensor network changes every time. Sensor networks are more suspected to the use of broadcast communication paradigm The power management is another major challenge which can be in the terms of battery power and computation power. Identifying the sensor node globally is another overhead that occurs. We are concerned more about the acoustic communication than the terrestrial wireless network communications [1]. This may increase the challenges faced by the network as the requirement of the network that should be satisfied by the network depends on the use of large number of lower sensors with minimal energy consumption by the efficient use of the power and the memory. Data aggregation is one of the major parts of an efficient network as it helps in clustering the nodes to avoid the collision of data generated from different nodes. A fault tolerant network makes use of the power in a better manner by configuring periodically. As in the terrestrial networks the electromagnetic waves cannot propagate with the same speed in the underwater sensor networks. As there are several differences in the characteristics of the electromagnetic and acoustic channels which we use to communicate in underwater. The application of the underwater sensor networks are distributed among various domains such as environmental monitoring, underwater exploration, disaster prevention, assisted navigation, tactical surveillance, and mine detection[2].

Routing in underwater sensor networks hold a large importance due to the difference between the characteristics of the acoustic communication to that of the radio-magnetic waves. Various protocols have been designed to satisfy the different requirements of the acoustic communications such as delay efficiency, bandwidth efficiency, reliability, cost efficiency, delivery ratio. But the major requirement that have been highlighted is energy efficiency. Energy efficiency depends of many metrics which should be considered while designing the protocol. And we aim basically at helping the protocol designers in providing an overview on the existing protocols and the energy efficiency techniques that can be used in underwater environments.

Rest of the paper is organized as follows: In the section [2] we discuss the various studies related to the energy efficiency optimization techniques. The characteristics of the underwater acoustic communication is described in the section [3] The various differences between the terrestrial and underwater communication have been discussed in the section[4].In section[5] the various existing energy efficient protocols have been described. In Section [6] we discuss the future direction of research.

II. RELATED WORK

There have been several research routed towards energy efficiency in terrestrial wireless sensor networks [3].Studies have progressed significantly to find methods to support the development of energy efficient protocols in wireless sensor networks. However most such methods are not directly applicable in underwater sensor networks area .Research efforts are progressing slowly towards creating protocols which are energy efficient but this is rendered harder because of the

major constraints such as propagation delay, limited bandwidth and higher error bit rate. The goal of [2] is to create awareness on the various unique challenges that UWASNs face as compared to terrestrial sensor networks due to the unique characteristics of the underwater medium and acoustic propagation through it. There are studies on the various acoustic channel characteristics and the inter-relationships among them in [4][5] and how it effects the energy efficiency. A survey on the energy efficient network protocols is attempted in [3] defining the sources of power consumption as well as conservation mechanisms. In [6] a general survey have been done on the routing techniques in underwater sensor networks Here in our paper we are focused on the energy efficiency techniques used in underwater sensors and the classification of the these protocols headed towards the future research attempts in energy efficiency.

III. CHARACTERISTICS OF ACOUSTIC CHANNELS

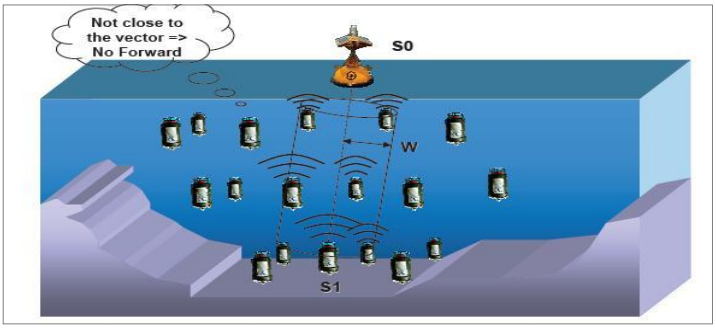
The main characteristics of acoustic channels that are considered as challenges in the field of underwater sensor networks arise due to the larger propagation delay, much lower bandwidth, the higher bit error rate probability. High attenuation is due to the loss caused by the attenuation by absorption in the medium and the wave front spreading. The spreading can be spherical or cylindrical depending n the depth and other medium characteristics. The speed of underwater acoustic propagations is considered to be lesser than terrestrial networks that use electromagnetic waves by five orders of magnitude. The acoustic channel has higher attenuation which is frequency depending and thus causing lower bandwidth. Reference [5] mention absorption coefficient as one of the main factors that limits usable bandwidth at a given distance as it increase with frequency. The much higher phase and amplitude fluctuations in underwater medium also lead to higher bit error rate in underwater sensor networks.

IV. DIFFERENCE IN UNDERWATER ACOUSTIC COMMUNICATION AND TERRESTRIAL NETWORKS

One major difference between the terrestrial WSN and underwater WSN in the communication speed. When terrestrial network communicate with radio waves, in underwater WSN radio waves are attenuated and replaced by the acoustic communications where the light travel at the speed of 1.5 x 10^3 m/s which is lower by five orders of magnitude compared to the radio waves. In under water acoustic wireless senor networks replacing one charging the power sources is practically impossible than in terrestrial wireless sensor networks. The corrosion of the nodes is a threat to deployed nodes in the underwater. The nodes move in 3D volume in wireless sensor networks. When compared to the terrestrial networks where the movement is in 2D space. The data rate of the terrestrial wireless sensor networks genuinely is higher compared to the underwater sensor networks. In terrestrial network we assume the energy consumption is low compared to the underwater sensor networks as nodes are deployed sparsely in aquatic environment and hence need to transmit data over larger distances. The communication GPS based localization mechanisms are not supported by underwater WSN at high frequencies which is possible with terrestrial networks.

V. ENERGY EFFICIENCY PROTOCOLS

Energy efficiency in terrestrial networks [3] have been studied and many protocols have been proposed, designed and proven. In underwater sensor networks the energy analysis is based mostly on the characteristics of acoustic channels that play an important role in energy consumption and lifetime of the sensor nodes [4]. In [6] a vast survey is presented on the existing routing techniques in underwater acoustic communications. They have also classified the protocols based on their proficiency in packet delivery ratio and this gives guidance in finding the protocols that are targeted at energy efficiency at the cost of other factors. Energy efficiency protocols can be classified into three based on the techniques they use for the design such as: Clustered protocols, Transmission relay based protocols and vector routing protocols. The vector routing protocols helps in avoiding the routing table and network wide calculations as in traditional methods. Clustering is another most fruitful attempt in achieving energy efficiency but the mobility of underwater nodes poses a threat in creating the boundaries for clusters. Transmission relay protocols are based on a set of nodes called the relay nodes which are considered to be interface nodes between the source and sink..



A. Vector based routing (VBF)

Vector based forwarding [7] is a location based routing protocol which carries no state information and only a small fraction of node involved in routing which helps in reducing the energy consumption. The interleaved paths are used for routing to provide robustness. This protocol is based on the self adaptive algorithm for discarding low benefit packets and increasing energy efficiency. The node mobility is also achieved in range of 3 m/s -1m/s. Each packet carries the positions of the sender, the target and the forwarder (i.e., the node which transmits this packet). A node computes its

relative position to the forwarder by measuring its distance to the forwarder and the angle of arrival (AOA) of the signal all the nodes receiving the packet compute their positions. If a node determines that it is close to the routing vector enough (e.g., less than a predefined distance threshold), it puts its own computed position in the packet and continues forwarding the packet; otherwise, discards the packet. All the packet forwarders in the sensor network form a "routing pipe": the sensor nodes eligible for packet forwarding. Each packet contains a RANGE field: a pre-defined threshold used by sensor nodes to determine if they are close enough to the routing vector and eligible for packet forwarding. Sink can utilize the source location information carried in the packets to determine if the source moves out of the targeted scope.

B. ***Distributed Minimum Cost Clustering Protocol (DDD)***

In this protocol [8] where the collector nodes are defined as dolphins and the sensors exploit one hop communications toward dolphins where the sensor deliver data only at a distance of one hop. The dolphin admits its presence by sending beacons to the sensors. Once the sensors find the presence of dolphin the data is transmitted to the dolphin from other source sensors and once the dolphin reached the distance of the sink it delivers all the collected data. Reducing the number of dolphins deployed is an essential need for reducing the cost of the networks. But reducing the number of dolphins deployed may effect the collection of the data. We determine the efficiency of this protocol in increasing the lifetime thereby reducing the energy consumption based on the event delivery ration and Delay. Event delivery ratio is defined as the total number of events collected by the dolphins out of the number of events generated in the area. Delay is defined as the average delay occurring between the time an event is generated and the time spent by the dolphin. The sensed data reduce the energy consumption by sensing the data when the dolphin is only at one hop distance.

Energy Optimized Path Unaware Layered Routing (E-PULRP):

In paper[8] a new protocol have been proposed that doesn't depend on the location information, fixed routing table/periodic flooding or time synchronization works in a distributed fashion. It consists of two phases. In the first phase al layering structure is presented with the set of concentric spheres around the sink node. The radii of the concentric spheres and the transmission energy depend on the minimum overall energy expenditure and the probability of successful packet transmission and minimum overall energy expenditure. In the second phase the intermediate relay nodes are chosen by the layering phase. Here the packet transmit occurs in multiple hops where each hops terminates at a anode in the next lower layer and on-fly routing algorithm for packet delivery from the source node to sink node across the identified relay nodes. The multi path or loss of connectivity due to the node mobility or underwater currents is reduced. Here the total energy expenditure is reduced as the number of layers increase initially but when it increase after a limit the overhead of transmission and reception comes into play.

A Mobile Delay-Tolerant Approach (MCCP):

A distributed minimum-cost clustering protocol (MCCP) [9] is proposed based on the assumption that node clustering is a flexible method of reducing the energy consumption. MCCP is a protocol where all the nodes can act as cluster heads with the help of the neighbor nodes. The energy consumption of a node as a cluster head is evaluated based on the total energy consumption of the cluster, the residual energy of the cluster head and cluster members and the distance of the cluster head to the uw sink. Here we use minimum cost clustering i.e. the cluster members are selected in such a way that the overall cost of the cluster remains minimum. The overall cost of a cluster is based on the intra cluster cost were we find the energy consumption to send a packet from a member to the cluster head and the relay cost that describe the energy consumption of the cluster head to send the packet to the sink. The protocol consists of two stages: the initialization stages were the candidate clusters are selected and the execution stage were out of the candidate nodes the node with minimum cost is selected as the cluster head. The protocol is compared against the HEED hybrid protocol in adhoc networks and is considered to be more energy efficient.

Temporary cluster based Routing [TCBR]:

Temporary cluster based Routing [TCBR] is considered as one of the energy efficient and scalable routing. Multiple sinks will deploy on water surface used as destinations and data received at any sink will be considered as successful communication as they use higher bandwidth and lower propagation delay due to the radio communication. There are two types of nodes used in the protocol such as ordinary node and courier node. Ordinary node deployed from water surface to sea bed at different depth levels with the buoyancy control .

The number of ordinary nodes used depends on the application. Other than ordinary nodes courier nodes are implemented for collecting data from the whole network. Courier node reach different depth of water through the piston modules that are used to ensure its presence it sends hello message to the ordinary nodes available. The hello packets that are transmitted can be forwarded until the courier node reaches the ordinary node and will collect the data in a buffer.

VI. CONCLUSIONS

Routing in sensor networks becomes a more challenging when we consider underwater sensor networks due to its unique behavior. In this paper we have summarized the research results on energy efficient techniques utilized save energy and thereby increase the lifetime. We have observed the protocols under the main three energy technique classifications. We also have included a table (Table 1) comparing the protocols based on the mobility scalability, their disadvantages and advantages they posses.

FUTURE DIRECTIONS

One of the future research areas will be on energy efficiency techniques in the presence of node mobility of nodes. Most of the above discussed protocols are suitable for a static network model. It would also be worthwhile to focus on the trade off involved in opting for densely populated networks with nodes carrying less energy against a network that is sparsely populated with high energy nodes to find out which will be more energy efficient. From the overall network energy efficiency point of view the cross layer optimization of the nodes in a network helps in the energy efficiency of the networks. Cross layer optimization can be adopted in routing protocols in many ways .Reference [12] aims at the different cross layer design that can be adopted in the layered protocols and in [13] some of the existing cross layer designs have been discussed. Paper [14] discuss a cross layer design used in the acoustic frequency identification application. A lot of research work will be focuses in these directions in the future.

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TABLE I

COMPARISON OF ENERGY EFFICIENCY PROTOCOLS

Routimg Protocol	**Energy efficiency technique**	**Mobility**	**Scalability**	**Advantage**	**Disadvantage**
VBF	Vector Routing	Support mobility	Provide scalability	Accomplish energy-efficient,robustness and node mobility	Is not compatible with different requirements
DDD	Clustering	Mobility granted to dolphin nodes only	Supports scalability	One hop communication is provided as method for energy consumption	Loss of packets occurs due to random movement of dolphin nodes

E-PULRP	Transmission relay	Mobility is granted initially later network become static	Supports scalability of network	Robust against issues like multipath and loss of connectivity	Through-put reduces and propagation delay increases
MCCP	Based on transmission relay distance and clustering	Node supports passive mobility	It supports scalability of network	Avoids the formation of hotspots around the sink	No defined boudaries for the clusters as nodes are in continuos movement
TCBR	Clustering	Doesn't support node mobility completely	Supports scalability of network	Packet delivery ratio increases	Duplication of packets increases

