Energy Efficient Routing Protocols and Efficient Bandwidth Techniques in Underwater Wireless Sensor Networks – A Survey

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Abstract— **The underwater wireless remote sensors convey messages in a range, where there is no possible human intervention. It is difficult to replace the battery in order to sustain energy in an acoustic environment. Moreover, considering the environment, solar energy cannot be used to recharge for batteries. These sensors are required to be awake for an extended period, taking in consideration that they have constrained energy limitations. One of the difficulties in submerged remote sensor systems is the uneven utilization of the energy resources. This will eventually result in lessening the lifetime of the sensors in the underwater networks. When compared to regular wireless sensor networks, Underwater Wireless Sensor Networks (UWSN) have a harsher surrounding, which could be translated into high energy constraints, low bandwidth, decreased throughput, and propagation delay. In multi-hop communication, the distance between the anchor node and the normal node is more considerable; which leads to more consumption of energy. On the other hand, since the distance is longer, it results into signal attenuation, ending into frequency power loss. The speed of the sound in deep ocean should be considered as the depth of the ocean increases. The variation of the speed of the sound results into this specific loss. A typical power spectral density occurs when the combined attenuation and noise are combined. Resulting into a decline of 18 dB within the duration of ten years. Among the layers of acoustic sensor network physical UWSN conventions are outlined in a manner that the energy utilization is compensated. While packets are being forwarded, the energy consumption must be less or balanced, else energy holes are created. In such cases, the energy efficiency, lifetime, and throughput are expanded. In this paper, we are summarizing most of the current energy based routing protocols. The provided information could be useful to analyze and design protocols for wireless underwater sensor networks by reducing energy consumption.**

Keywords: *UWSN, energy efficiency, throughput.*

I. INTRODUCTION

Nowadays, UWSN are emerging despite challenging applications such as, underwater environment monitoring, pollution monitoring, surveillance of coastal areas, and extraction of rare minerals. Regular underwater architecture consists of a wide range of sensors deployed in oceanic surfaces to gather information within a particular environment. The sensors are dynamic and move according to ocean currents. Underwater is often considered a harsh environment where sensors may move from a particular point to an unexpected location [1]. The limitations of underwater environments include less battery power for sensors added to the fact that it is difficult to the batteries in the deep ocean. Static sink also creates hotspot problems in which the closest sensors to the sink die at an earlier stage leaving some areas unmonitored. This can be mitigated by mobile sinks in deep waters. Sensors are deployed both in the surface and inside the water, where the lowest depth sensors are data forwarders; they weaken quicker than the other nodes in the network, thus creating holes in the network. This phenomenon is called energy hole, it reduces network efficiency and lifetime.

Under the water, radio and optical signals do not propagate and are also affected by absorption loss. Instead of these signals, acoustic signals are used, as they can travel for a longer distance [2]. Due to the manufacturing cost and the large area to cover, the sensors are deployed sparsely. The common problems in UWSN are: limited bandwidth, high propagation delay, lower frequency, large bit error rate, and multipath fading. Transmission happens directly as well as by multi–hops technique. Which results into a larger consumption of energy in comparison to the receiving side. Proper routing mechanisms must be specified, as this is a challenging process for routing the information packets. In this paper, energy effective routing protocols for underwater are studied to overcome the previously described problems.

II. RELATED WORK

For Azzam et al. [1], the network region is subdivided into equal sizes, such as sparse region and dense region. The dense region consists of more sensors compared to the sparse region. The process of introducing cluster head in dense region and mobile sink in sparse region improves the network's life time by saving energy. Thus, sparse aware energy efficient clustering protocol will improve the lifetime of the network by forming clusters in the dense region and mobilizing the sink in the sparse region.

Network model: the underwater region is evenly divided into ten regions. The sensor nodes are positioned randomly in a dynamic way. As the sensors are in the underwater environment. The sink is suspended at the centre of the network region and above all the nodes remain static. Apart from the static sink, two sink mobile move inside the network region. Sink Mobile1(MOS1) moves in the sparse region circumference and then changes its position for every cycle. Sink Mobile2 (MOS2) moves only in the circumference of one sparse region till all sensor nodes are dead.

The procedure to find the two types of regions (sparse and dense): total network region is subdivided into ten equal parts. Let N-total number, R- number of regions, n- number of nodes in single region, r- subdivided region
Lr- left side region, Rr- right side region.

The left side is separated into 5 regions (Lr1, Lr2, Lr3, Lr4, Lr5), the right-side region is divided into 5 parts (Rr1, Rr2, Rr3, Rr4, Rr5)

- Sensor deployed region is taken into account (R).
- Each region is subdivided into ten equal parts (Lr1 to Lr5, Rr1 to Rr5).
- No. of nodes in each subdivided region is calculated (n).
- No. of nodes in a region is compared with the other regions.
- If the number of nodes is less that the other region, it is a called sparse area.
- If the number of nodes is more than the other region, it is called dense area.

The Cluster Head (CH) is selected for four most densely deployed nodes, a node with lowest position and more residual is selected as CH, data is sent to CH, then it performs the aggregation of data and transfers it to a nearby sink.

In, the Dual Sink Efficient Balanced Energy Method [2], a class of sensors and two sinks are employed in a specific region. Energy from all the nodes are categorized into Energy Level Numbers (ELNs). With a minimum distance, relay nodes are selected by the sensor nodes. Inside the transmission range, data will be forwarded to the particular sink. In a similar way, the utilization of energy is balanced with the increased network's life time and throughput. The protocol has two sinks deployed inside the water. The first sink will be establishing a path, while the other one transmits the data. The path provides connection between sensor nodes. The nodes share information using links.

Phase 1: A path is based on an optimum value of the threshold. Forwarder nodes are used for the transmission of packets. Depending on the depth, the neighbors are selected and only a maximum of three packets can be sent at a time.

Phase 2: Paths provide a way for transmission of data. All nodes will have the same energy. Initially multi–hops communication is used to transfer the data between the neighbor nodes. If the node has a greater energy than its neighbor node, then it is called a relay node. Nodes with less energy level number and depth are selected for transmission. If the nodes are close to the sink, then it gets an extra energy level value and sends data through direct transmission. The limit is to save energy. Every node must find its respective sink, so that each node has a balanced energy consumption. By this method many chains are formed. With the help of dual sink method energy is balanced and throughput is increased.

In Cluster Based Approach [3], the nodes will compete with each other to become a Cluster Head, which is elected based on the distance. The clustering approach in routing protocols increases the stability period of the network. The deployed nodes will broadcast their status so that the load is equally distributed and the energy consumption is minimized. Thus, consumption of energy in each node is equally utilized, as each node has the same probability to be a Cluster Head.

LEACH: Low Energy Adaptive Clustering Hierarchy. This phenomenon is used to randomize energy nodes and distribute it equally to other nodes from the cluster head, in order to optimize the system's stability. There are two phases: advertisement phase and cluster setup phase. In the first phase, the nodes should decide about the cluster head depending on the returned value. The nodes inform the other nodes about the cluster formation in the second phase. With the help of Time Division Multiple Access, the nodes are informed as packets and should be transmitted according to their priorities. The final phase is the data transmission phase, where all the information from other nodes is sent to the cluster head and then transmitted to the Base Station.

LEACH has few disadvantages, which have been overcome by Energy Balanced Routing Algorithm: when the node with maximum energy consumption is used, it weakens quickly and becomes unstable for functioning. In order to avoid this, the most frequent energized nodes and the rest of the system's energy is taken into consideration. The CH cannot transmit relevantly at all times, and so a node called "Cooperative" is formed.

Clustering Depth Based Routing for Underwater Wireless Sensor Networks (CDBR):

1) The architecture is as follows: a static sink is at the surface and the nodes are deployed inside the water surface. The nodes are classified into three categories: Cluster head node, normal and dead node.

E – Energy, T – Threshold; Optimal dist. – 20; R - Random Number
E = 0; Dead Node
R = 0 and 1 is generated by each node
R › T and CH › optimal distance; Cluster Head Nodes
R‹ T, CH ‹ Optimal Distance; Normal Nodes

2) Deployment of Sink: There are 2 classification of modems
   - Sensor node communication– Acoustic
   - Base Station communication – Radio Frequency
3) Deployment of nodes: nodes have constrained energy and they quickly weaken when they transmit information to the BS through the CH. They send a hello message and exchange data with neighbor nodes.
4) The election process of cluster head: First the nodes are elected
   - The election is as follows:

R › T and CH › optimal distance; Cluster Head Nodes

R‹ T, CH ‹ Optimal Distance; Normal Nodes

5) Forwarding Data: where respective nodes forward energy to the respective cluster heads. The transmission path takes the least path, and so this will consume less amount of energy. If the path is not in the transmission range, packet forwarding will be declined. This will reduce the back transmission. CDBR does not require all the information regarding the depth of the nodes, instead only the residual energy is taken into consideration. The clustering technique use minimum energy efficiently.

The cluster head is selected with the help of residual energy after the formation of clusters, as discussed in [4]. The system will have knowledge about the percentage of predefined clusters in the network. Hence, the cluster head should be closer to the sink compared to the distance between the other nodes and sink. Balanced energy technique is used to shift the cluster head between the transmission nodes.

In ocean depths, where a rough oceanic condition prevails, it is difficult to transmit the signal and retain the physical properties of the link. In Underwater wireless sensor, the networks lifetime is considered. Hence, energy efficiency is one of the most important constrains in UWSNs. The Energy based hybrid clustering is a protocol which deals with the energy efficiency and quality routing. It has been represented as DB-EBH (Energy balanced by depth) protocol. Where the energy efficient balance mechanism is used to increase the lifetime of the network. The relay node is selected to send data to the sink among the nodes having low depth and maximum energy residue. When the relay node defines the weaker energy grade, it will change its transmission mode from multi-hop to direct, and the same will be followed by the neighboring nodes when they receive the control packet. Nodes closer to the sink need time to change their transmission mode than the farther node. By adopting this method, they consume less energy. Energy Balanced by Depth (DB-EBH) inspired EBHC deals with the same and contains energy efficiency in underwater. These sensor nodes are arranged in the cluster by themselves and choose a cluster head. The cluster head should have the minimum depth and maximum residual energy.

The Cluster head promotes data aggregation and decreased the number of transmissions. The energy dissipation is reduced and the lifetime of the network is increased. In this protocol, the energy is equalized according to the transmission mode. Which reflects fallen grade of energy, which makes the node transmit by direct transmission. This is the efficient technique to improve the energy of the cluster head, and improve the lifetime of network and the amount of data transmitted.

On the basis of direct and multi-hop communication, a hybrid approach is used in [5]. DB-EBH does linear random employment of nodes. In this network, the cluster head is responsible to distribute the energy load evenly, aggregate data, and send data to the sink. Through clustering, the reduced transmission is achieved, thereby reducing the energy loss and the life time of the network is increased. Neighbor nodes are selected based on the depth priority, thereby the performance of DB-EBH is increased with enhanced energy, as well as the network lifespan and throughput. First the nodes energy is divided into smaller blocks, known as energy grades. A single block is separately defined as energy gradation. High energy grades lead to a smaller block energy. This leads to frequent switch between the transmission modes, and causing difficulty in packet forwarding over the network. Energy grades with small numbers lead to huge energy blocks that cause the transmission mode to switch to multi hop communication. This affects uneven energy consumption. The problem is due to the multi hop transmission that dissipates less energy in comparison to the direct transmission.

The two important considerations are as follow:

a. Nodes in deeper part are referred to as upstream nodes;
b. Consecutive node following the deeper node in downward direction is referred to as downstream nodes.

The process of transmitting packets:

- Every node has its residual energy grade
- When the energy grade is less in any node, it alerts the downstream node to release the control packet towards it.
- Packets have information about the node's ID and reference number of residual energy grade.
- Then, downstream node checks whether the energy grade is greater than the neighbor node.
- When its energy grade is high, the node informs the downstream node to get packets from high depth neighbor nodes and change the transmission mode to the direct transmission mode.
- This results in the reduction of transmission load in the downstream, which remains in multi-hop transmission so it will transmit only the sensed data.
- It is shown that downstream nodes consume less energy than upstream nodes.
- When the energy grade number is similar, the transmission is switched to multi-hop, and the cycle continues.

III. Problem Identification

Some of the major problems identified in underwater acoustic sensor network is the lower bandwidth and frequency, limited battery power, high propagation delay, large bit error rate, and multi-path issues. Underwater wireless sensor networks architecture constitutes of sink at the water surface, which is static in nature and the sensor nodes are employed in an irregular manner.

In UWSNs data is forwarded from the lowest sensor node, so these nodes will die and a routing hole will be formed. This results in unstable loads of data being forwarded and is defined as energy hole. Energy hole leads to death of sensor nodes in short span of time when compared to the rest of the nodes in the network due to what has been described, a coverage hole develops and these areas remain unobserved or un-sensed.

If the nodes forward data via multi-hoping to sink, it may lead to data corruption due to noise. The node which are in longer distance needs more energy to transfer data either through direct transmission or by multi-hoping transmission. On the other hand, it is not applicable to transmit the data for longer distance by direct transmission, as time delay is produced in hop by hop transmission. Since high energy is required to send the data packets to the destination, there is reduction in the network lifespan and throughput.

IV. Techniques To Increase Bandwidth

Push System:

Among various waves, radio wave has poor propagation characteristics in underwater. Hence, push system techniques works efficiently in a high latency environment systems. [6] The basic concept used in the push system is “learning automata". The learning automata is a method based on the previous output. Thus, the current time of last broadcasted item, length of the item, and the probability for the item length to be erroneous. As a result, if an item fails to broadcast, it is represented as -1. Number of mobile clients supported depends upon the bandwidth, transmission bit rate of the feedback, and bit energy to noise power spectral density. Thus, only a small bandwidth of about 200 Hz is used for feedbacking the remaining 9.8 kHz are used for transmitting the items. All the above-mentioned parameters for the feedback are repeatedly monitored and stored in the database. Thus, the bandwidth efficiency is improved.

Adaptive Bandwidth Adjustment:

Medium access control is very easy to implement. This technique leads to low overhead thus the efficiency is improved. The band adjustment is performed based on the network traffic and congestion in common channel [7]. The traffic load in the Common Control Channel (CCC) is accessed. Based on this traffic load the frequency band is adjusted in the control channel. If the congestion occurs in the control channel, then the node will be notified about this congestion. Thus, the increased bandwidth is demanded from the in-band channel. When the CCC is less utilized, the frequency is reduced in the data channel by the in-band channel. All these tasks are accomplished through the congestion control and bandwidth adjustment technique.

Lloyd algorithm and Bit Loading Algorithm:

This technique works with limited bit error rate and symbol data rate [8]. The algorithms proposed achieve the maximum data rate and system margin. The algorithms described here to achieve bandwidth efficiency and the power consumption are the bandwidth efficient bit loading algorithm and Lloyd algorithm. These techniques efficiently work together to achieve the ultimate result. These techniques are based on the obtained feedback, which is simultaneously simulated to get the desired result.

Energy Efficient Aggregation Bandwidth for Selection Method:

The aggregation bandwidth and energy efficiency are inversely proportional [9]. As the distance increases the efficiency of the energy reduces. Thereby, causing loops in underwater sensor networks. The major goal is the optimization of energy from the transmitter to the receiver. For example, if the distance is above 5 km the energy efficiency drops, since the bandwidth obtains its optimizing value. This technique can be used under the constrained condition of minimum communication rate and maximum transmission power.

Frequency - Domain Equalization:

This technique is used for efficient bandwidth equalization from acoustic communication using a single carrier [10]. The physical signal is converted into the electrical signal and a microphone is used for obtaining the sound waves and then the difference in distortion is obtained. This simultaneously improves the performance of bit error rate. The major problem is the inter-symbol interference caused by the multi-paths delay and the lack in the propagation of the signal. The channel is unstable and less robust. This technique provides lower complexity and better robustness and make it usable by single and multi-hop communication. This method is used for overlap save method. There are big blocks of size 'N' which are divided into major small sub - blocks of length 'N_s'. Each and every block has variations where detected symbols are valid. Thus, the traffic between the blocks and the transmission are greatly reduced.

Network setup phase and efficient data transmission:

A reliable and energy efficient network is designed in such a manner to avoid the horizontal communication among the ordinary nodes. The nodes in the same depths are considered as the ordinary nodes. This is achieved by having two nodes such as ordinary secondary node and sink node.

RF modem and the acoustic modem [11]. The horizontal communication takes place through the RF modem and the rest of the communication takes place through the acoustic modem. With this information, we can avoid the horizontal communication between the ordinary nodes. The residual energy is shared among the neighbor nodes, then sink will send the hello packet to a node, after receiving the hello packet with the help of Time Of Arrival (TOA) [11]. The distance is calculated and recorded and this is repeated until the hello packets expires. This process is carried out to avoid the ordinary nodes. In the transmission of data, packets are transmitted to the sink through the multi-hop transmission mode. Thus, every node at the bottom of the ocean will have hello packets and these hello packets will have the information about the distance. Based on the minimum distance information the node will transmit the data to the sink. Through this process, a high-energy efficiency is achieved.

Void avoidance technique:

In this technique, each node will know its depth as its vertical distance from the water surface [12]. With the help of distributed beacon nodes, the hop count will be known. The nodes will move in the direction of the water current. In the case of a sink, when the destination is permanent, Opportunistic Void Avoidance Routing operation is used when there are multiple destinations with the usage of multi-sink. Void avoidance techniques are initiated and established from the sink to the nodes. To attain the successful information transfer and the discovery of neighbor node, each node will periodically broadcast the beacon which has the hop count information, where by the routing table is updated. It uses hop by hop forwarding to deliver packets to the sink. Each packet holder uses the current information of the hop count and assign the forwarding set. Which results in the avoidance of hidden terminal problem. Therefore, the node with the highest priority transmits the packet after hearing the transmission. Through this technique, we are lowering the hop count and increasing the energy efficiency.

TABLE 1: SURVEY TABLE

S.No	Title	Problem	Objectives	Technique	Advantages	Results
1	Routing Protocol for Low-Power and Lossy Networks	Increased latency over high propagation delay.	To use the required bandwidth resource efficiently in underwater acoustic sensor networks.	Push system	200 Hz of bandwidth is used for feedback, remaining 9.8 kHz is used to transmit item.	By efficient utilization of bandwidth, the overall performance is improved by 17%.
2	Dynamic Control Channel MAC for Underwater Cognitive Acoustic Networks	High overhead and congestion.	To adjust the bandwidth based on network traffic and congestion.	Adaptive Bandwidth Adjustment.	The node will increase the control channel by adding non-active PDC on it.	Smartly adjust the bandwidth of its control channel by adding frequency band from the in - band channel.

S.No	Title	Problem	Objectives	Technique	Advantages	Results
3	Bandwidth - Efficient Bit and Power Loading for Underwater Acoustic OFDM Communication System with Limited Feedback	Only few bits of feedback can achieve almost the same performance as a perfect feedback, and can significantly reduce the required SNR.	To maximize data rate and system margin maximization.	Bandwidth efficient bit loading algorithm and Lloyd algorithm.	BER constraints are maintained with both perfect feedback and limited feedback.	Iterative loading algorithm is an effective approach to achieve minimization of transmission power and bandwidth efficiency.
4	Energy - Efficient OFDM Bandwidth Selection for Underwater Acoustic Carrier Aggregation Systems	Unpredictable ambient noise for variant distances.	To optimize the transmission energy utilization by feeding back the optimal bandwidth value from the receiver to the transmitter for the different distance settings.	Energy efficient aggregation bandwidth for selection method.	Optimal aggregation bandwidth is determined given the constraint condition of minimum communication rate and maximum transmission power.	Aggregation bandwidth using carrier aggregation has an optimal value to maximize the energy efficiency.
5	Bandwidth Efficient MIMO Underwater Acoustic Communications with Frequency - Domain Equalization	Excessive long multi-path delay spread and frequency - dependent propagation attenuation leads to severe Inter Symbol Interference (ISI).	To mitigate the Inter Symbol Interference and improve bandwidth efficiency and track channel variation.	Doppler Effect, time domain decision feedback equalization with the phase locked loop.	Overhead of data transmission for channel, the estimation is greatly reduced and the variation of channels are effectively tracked in this channel estimation scheme.	Increases the data efficiency of transmissions and significantly improves the system performance.
6	Reliable and Energy Efficient Routing Protocol for Underwater Wireless Sensor Networks	Low bandwidth and issues related to physical layer such as high latency.	To improve energy efficiency.	Reliable and Energy Efficient Routing uses Time of Arrival to find node distance to its respective sink	REEP does not require detailed localization information of sensor node.	Extended network life time and reduced end-to-end delay.
7	An Opportunistic Void Avoidance Routing Protocol for Underwater Sensor Networks	Lower bandwidth, longer propagation delay, dynamic topology, high error rate.	To improve packet delivery.	Opportunistic Void Avoidance.	Efficiently bypassed all kinds of void areas with the lowest possible cost (including energy and delay).	Improved Packet delivery ratio, less energy consumption, and average end-to-end delay.

V. CONCLUSION

In this paper, we have surveyed various protocols for routing and bandwidth optimization techniques. We have discussed their advantages, limitations and contrasted them based on their adopted techniques. Our study encompassed various research areas where the underwater sensor networks show many constraints: like signal propagation, usage of energy, bandwidth utilization, etc. We have summarized the most significant constraints in Underwater Acoustic Systems and how to mitigate them.

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