Delay efficient Layer by Layer Angle Based Flooding Protocol (L2-ABF) for Underwater Wireless Sensor Networks

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Abstract

The advancement of acoustic modem technology in providing better data rates and more reliable underwater wireless communications has motivated many researchers to create various algorithms to support such technology in a better way. These continuing researches have greatly improved the underwater communication performance in the last two decades. However issues such as inefficient horizontal communication between the sensors nodes on same depth level, high end to end delays between source and sink nodes, propagation delay, as well as poor data delivery ratios are still posing challenges for effective and efficient data packets routing. In this paper, we present a novel Layer by Layer Angle Based Flooding (L2-ABF) routing protocol to address some of these challenges for the partially connected underwater communication environments.

Keywords: *propagation delays, Layer by Layer Angle Based Flooding, Routing algorithms, UWSN.*

1. INTRODUCTION

The applications of underwater wireless sensor network (UWSN) are becoming popular for exploring areas in ocean which contain commercial resources like oil/gas, nourishment products, valuable minerals, etc. UWSN is also commonly used for preventing oceanic accident like disastrous pollution, or in submarine detection, and in tsunami warning systems. Although UWSNs resemble the terrestrial wireless sensor networks, they are in fact very much different in quite a number of aspects [1,2]. Firstly, communication mediums are different where UWSN uses acoustic signal but terrestrial sensor network operates on radio waves and it is already well known that radio wave is generally not suitable for underwater environment [3]. Secondly, most nodes in UNWS will move passively with water current (except some nodes which are fixed at water surface or anchored at sea/river bed). This movement of the nodes may cause rapid change in the network topology. So the existing routing protocols for static networks are not suitable for this type of environment. Thirdly, energy consumptions are different for both type of WSNs. In general, UWSN are more power hungry than the terrestrial based network. Furthermore there is seldom an effective mechanism available to recharge or to easily replace the batteries in underwater sensor nodes.

From energy perspective, packets forwarding over multiple short hops are preferred instead of long links. Multi-hop data deliveries have been proven to be more energy efficient for underwater networks than a single long hop [4]. However, it is observed that packet routing over more numbers of hops ultimately degrades the end-to-end reliability especially for the harsh underwater environment. In many applications, UWSN are deployed by a single entity with economical hardware, thus causing strict interoperability constraints with the existing standards.

A lot of researchers have been focusing on designing efficient protocols to adapt to the intrinsic characteristics of underwater communications. In the last decade, many routing techniques have been proposed for UWSN such as those found in [5–10]. Some routing techniques, as in [5]

& [6] are based on special network setup and hardware, those in [7] & [8] required some geographical location information of sensor nodes, and the types in [9] & [10] are based on some assumptions.

In this paper, we proposed a novel routing protocol called Layer by Layer Angle Based Flooding (L2-ABF) Protocol for UWSN. Although some angle based flooding techniques already exist, our technique may have some advantages over them in these aspects:

- L2-ABF does not require any location information of sensor nodes.
- It does not depend on special network setup and hardware.
- L2-ABF used very simple angle calculation for flooding of data packets.
- It does not have constraint on sensor node deployment density in the network.

L2-ABF protocol is scalable, delay and energy efficient. It uses angle based flooding architecture in which multi-sinks are anchored on water surface to collect data and other data sensing nodes are deployed at deferent depth levels between sea surface and the sea bottom. Sensing node that have received data packets and try to forward to the upper layer nodes will use angle based cone-shape transmission coverage zone for transmitting the packets. The data packets are considered delivered when they reach one of the sinks on the water surface.

The rest of the article is planned as follows. In section 2 some related works are described. Section 3 is on the concept of L2-ABF and the contributions of this protocol. The proposed protocol performance and its evaluations are described in section 4. Section 5 concludes the paper.

2. RELATED WORK

Underwater acoustic networks have recently attracted a lot of interest in the UWSN research community. While some of the existing solutions in the radio-domain may be reused, the unique properties of the underwater channel usually required the development of dedicated solutions. Extensive work at the different layers of the classical protocol stack has been conducted by many. A good overview of existing networking protocols for underwater networks can be found in [11]. In this section, we focus on the work related to flooding, power control, and end to end delay.

Some routing protocols are found to be explicitly designed for angle based data packets forwarding for the underwater channel. A review of underwater network protocols up to the year 2000 can be found in [7]. Among the many routing protocols, Vector Based Forwarding (VBF) protocol was proposed to solve the problem of high error probability in dense nodes deployment networks. Here an idea of routing pipe, like in circuit switching, from the source to the destination is proposed for flooding data packets through this pipe. By this approach, packets retransmissions are decreased making VBF to significantly improve the energy efficiency.

In [12], a two-phase flexible routing solution for long-term monitoring applications based on the idea of centralized planning network routings and data paths was proposed. Later on, the same authors proposed a protocol that can handle both delay sensitive and delay tolerant applications. In this protocol, a cross-layer approach was adopted to create an interaction between the routing functions and underwater characteristics.

For location based routing, most of the protocols require (and need to manage) some full-dimensional location information of the sensor nodes in the network thus posing some challenges in UWSNs. Instead of requiring complete localized information the protocol, the method in [6] needs only the local depth information. Obtaining the depth information is not an issue. The authors suggested to equip each node with an inexpensive depth sensor. Their simulation results showed that, Depth Base Routing (DBR) can achieve high packet delivery for dense networks with reduced communication cost. However the problem here is, it does not show good results for sparse networks due to its greedy nature. In order to achieve same performance as for dense node deployment, some recovery algorithms need to be explored when the greedy strategy failed.

Researchers in [8] presented an idea of Focused Beam Routing Protocol for acoustic networks. Their routing technique assumed that every node in the network has its own location information. In addition, they also assumed that source node knows about the location of the final destination. However in reality not all source nodes have the location information of other source nodes in the network. Routes are established dynamically, during the traversing of data. Forwarding of packets from source node to its destination and the decision about the next hop is made at each step on the path after appropriate nodes have identified themselves. For performance checks, they focused on average end-to-end delay and energy consumption for each bit. In their simulations, the protocol performance remains close to the ideal case due to the minimum additional burden and less dynamic route discoveries.

The main difference between our proposal, the L2-ABF, and other geographical based routing protocols is that L2-ABF does not depend on full-dimensional location information. Instead, only use some assumptions on the nodes horizontal movement/sway.

3. CONCEPT AND CONTRIBUTIONS

The horizontal communication between the sensor nodes on the same depth levels is known to cause an increased in data routing path from lower layer nodes to the surface sinks deployed on the water surface. The large data routing path is highly likely to increase end to end routing delay in the underwater data transmission and brings along with it the higher energy consumption issues. The proposed L2-ABF protocol is aimed to reduce or eliminate the horizontal communication between the peer sensor nodes on the same depth level in the underwater sensor network. Angle based flooding architecture is used in L2-ABF to achieve this goal. The anchored sensing nodes flood the sensed data towards upper layer nodes using the calculated angle of $(\pi/2) \pm R$ on both sides of the angle cone where the cone angle range is always greater than 0 and less than π as shown in fig.1.

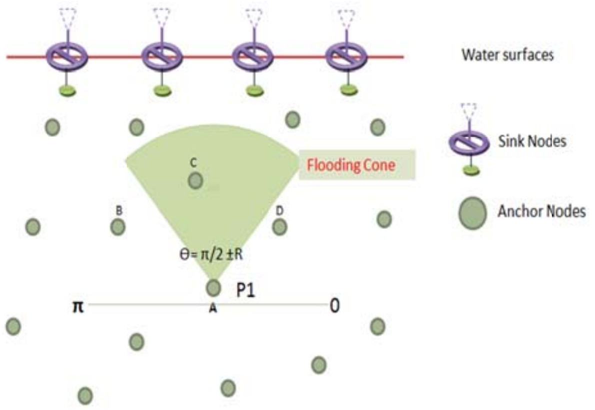


Fig. 1: L2-ABF angle base architecture.

3.1 Overview of L2-ABF

The angle base flooding architecture is used in the proposed routing protocol. This is a routing mechanism that does not based on location information of sensor node and is to be designed for energy-efficient multi-layer communication in underwater acoustic networks. In this routing mechanism there is no need for sender node to know their own location and the location of the final destination (sink) before transmitting the data packets. Using power level P_1, an anchor (data sensing) node e.g. node A, floods the sensed data towards surface sinks via the upper layer nodes using the initial angle of $\pi/2$. If there is no ACK from any receiving nodes then add some value of variable $\pm R$ to the initial angle to increase their flooding zone until the basic condition is meet ($0 < \Theta < \pi$). The range of value for variable R is (10 to 25) and selection of the values is depending on the movement of the nodes.

- If node movement is slow than increment of angle in flooding cone is fast.
- If node movement is fast than increment of angle in flooding cone is slow.

After completing one round of the angle increment for the cone, if there is no ACK from any receivers, node A will increase its power level to P_2 and repeat the same procedure. The maximum power levels are $P = P_1, P_2 \ldots\ldots P_{n-1}$. Here n is a variable which has finite set of values. Referring to Fig.2. Let's assume that node A wants to send a data to sink node. To do so, node A first selects its flooding zone by using basic cone angle of $\pm\pi/2$ and wait for ACK from possible receiving nodes.

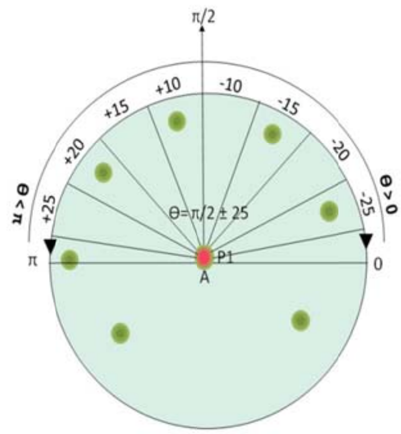


Fig.2: Increment of angle cone in L2-ABF

If there is no ACK received, node A will increase its cone angle by using the values of variable R and complete its round under the condition of $0<\Theta< \pi$. This transmission round is performed on initial power level P_1. If there is no ACK after completion of one round than node A will increase the length of the cone with the increment of power level to P_2 and so on up to the n^{th} power level and repeat the same procedure until the source node A receives an acknowledgement from a receiving node. The nodes inside the flooding cone can only acknowledge. In Fig.1 node C is inside the flooding cone and would be responsible to ACK node A upon receiving data from node A. If multiple nodes are inside the cone, then all nodes will acknowledge to node A.

3.2 Protocol Design

As mention earlier, L2-ABF uses flooding based approach. So it is very likely that multiple nodes are qualified candidates to forward a packet at the next layer. If all these qualified nodes try to flood the packets into the network, high collision and high energy consumption will result. Therefore, to reduce collisions as well as energy consumption, the number of forwarding nodes needs to be controlled. Moreover, due to the inherited multiple-path feature of L2-ABF (in which each sensor node forward packets in a flooding fashion using an angle based directional acoustic channel), multiple nodes may receive the same packet. Consequently it may send the packet multiple of times. To maintain energy efficiency, ideally only one node needs to flood the data packet. To do so, we used the redundant packet suppression technique.

Redundant Packet Suppression: To save energy and to reduce chances of packets collisions, redundant packets need to be suppressed. There are two major causes of redundant packets. One is that multiple nodes may forward same data packets. The other is that a node may send a same packet many times. We use a priority queue to reduce the number of forwarding nodes, and thus control the number of forwarding paths. To solve the second problem, a packet history buffer is used in L2-ABF to ensure that a node forwards the same packet only once in a certain time interval.

Data Packet Format: The packet format used in L2-ABF is illustrated in Fig. 3. The packet header consists of three fields: Sender ID, Layer Number, and Packet Sequence Number. Sender ID is the identifier of the source node. Packet Sequence Number is a unique sequence number assigned by the source node to the packet. Together with Sender ID, Packet Sequence Number is used to differentiate packets in data forwarding. Layer Number is the information of the recent forwarder which is updated Layer-by-Layer when the packet is forwarded.

ACK Message Format: To increase the data delivery ratio in L2-ABF, ACK message is used. The message format is illustrated in Fig.4. ACK Message contains three fields, Node ID, Receiving Tag, and Packet Sequence Number. Node ID is identifier of receiving node. Together Receiving Tag and Packet Sequence are used for originality and guaranty of received packet to the sender.

Sender-ID	Layer No	Packet sequence No.	Data

Packet Header

Fig. 3: L2-ABF Data Packet Format

Node-ID	Received-Tag	Packet sequence No.

Fig.4: ACK Message Format:

3.3 Algorithm: Data packet forwarding in L2-ABF

1. Node "A" has data packet and ready to send
2. select power level from P= [p_1 ,p_2 ,p_3.....P_{n-1}]
3. Check the Q2 //Q2 is buffer history
4. if (P in Q2)
5. Discard the packet // Packet already sent
6. END if
7. Check the value of Q1 // Q1 is priority value queue to forward data packet next
8. if (Q1 has greater value)
9. calculate $\Theta = \pi/2 \pm R$ // K is variable has set of values [10, 15, 20, 25]
10. Forward "P"
11. END if
12. if (ACK is received)
13. Go to rest mode //Acknowledge Node is Qualified for further flooding
14. Else
15. If ($R \leq 25$)
16. increase the value of variable "R"
17. Else
18. Go on step 2 and repeat all step // Select the next power level
19. End if
20. End

3.4 Power levels and Cone Length

As mention earlier, to save power consumption in L2-ABF, we introduce power levels control mechanism for flooding cone length with respect to each power level. Every node has finite set of values for power levels as P_n= p_1, p_2, p_3.........P_{n-1} and every power levels has specific increment for flooding cone length. The flooding cone length depends on the distance between the layers of node which is normally assumed to be 300m to 500m in the perspective of acoustic communication [11]. The width of flooding cone is dependent on the value of base angle and variable R as shown in Fig. 2. The range of values for variable R is ranging from 10, 15 ... to 30. It is used by the source node according to the behaviour of node movement. If node movement is fast than source node select the small values of R for flooding cone angle conversely if node movement is slow than select large value of R. The last value of R is used to restrict the width of the flooding cone. We know that when two nodes communicate horizontally, both are on the same level and the angel between them is (0-π). We applied restriction in our routing protocol to flood the data packets only in the area that is between the angles ranging from 0 to π, and the flooding cone angle must be greater than 0 and less than π (as shown Fig.2). Every node might attempts 5 rounds for each power level to find the next forwarder until it receives an acknowledgement from any other nodes.

4. PERFORMANCE EVALUATION

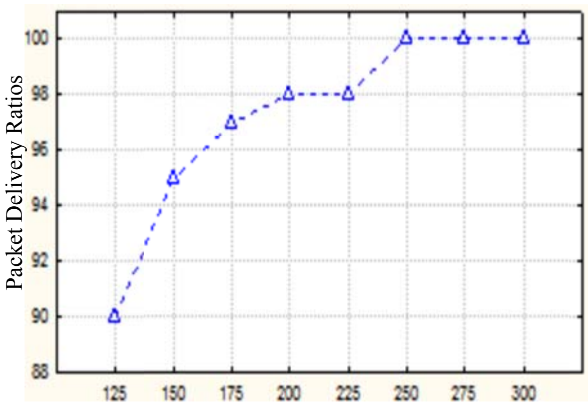
We check the performance of our proposed algorithm by using NS-2 simulator. During the simulation we considered 300 sensor nodes (both Sink and Anchor) deployed in a three dimensional volume of 1500 × 1500 × 1500m. The Sinks consider being stationary after deployed and Anchor nodes can move horizontally (swaying) with fixed motions. The Sinks are equipped with radio and acoustic communication hardware. We ignore the vertical movement on Anchor nodes. Simulations setting are shown in Table 1.

Table 1: Parameters setting and Descriptions

Items	Parameter Name	Description
1	Number of sensor Nodes	300(Sink/Floating)
2	Packet size	512 Byte
3	Channel type	Wireless
4	Medium type	Acoustic/Radio
5	Exploration area in 3D	1500×1500×1500m
6	Transmission Rang	500m
7	Protocol	AODV
8	Antenna Type	Omni
9	Bit rate	CBR
10	Transmission Rang	500m

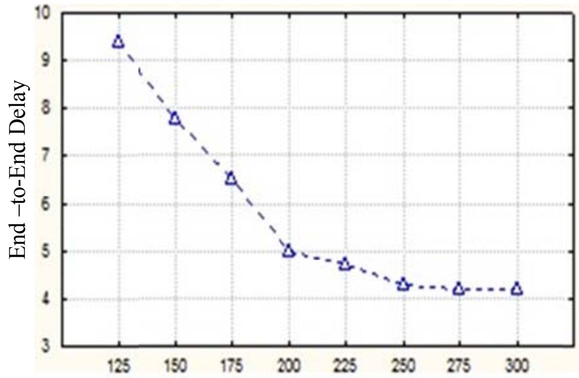
We have considered two performance matrices i.e. End-to-End Delay and Delivery Ratio to evaluate the effectiveness of our routing protocol. End-to End Delay is the average delay for all successfully received data packets at sinks on water surface. Packet Delivery Ratio is defined as the ratio of packets received successfully by all sinks on water surface as generated by all sensor nodes in the network.

The results in Fig.5 show that there is no serious effect on delivery ratio and the end-to-end delay in L2-ABF protocol with the densities of nodes increasing. The reason is that there is no need to maintain complex routing table for the location of nodes as well as no need to significantly reconfigure the nodes in the networks. In near future, we will compare these results with other well-known routing technique.



Number of Nodes

(a) Average Packet Delivery Ratios



Number of Nodes

(a) Average End-to-End Delay

Fig. 5: Evaluation Results

5. CONCLUSION

In this paper we present a novel routing protocol for underwater wireless sensor networks. The novelty of this protocol is that, it does not depend on full dimensional location information, or any special type of hardware configurations, and does need to maintain complex routing table. We deployed the idea of angle based routing instead of any source routing or the per-hop routing. The real beauty of L2-ABF is that, the data delivery ratios are not seriously affected by increasing the densities of the deployed nodes. The result shows that, it can achieve high delivery ratio (more than 90%), for dense networks with small delays. Our future plan is to extend our simulations with different parameters to compare with other well-known routing protocols for performance benchmarking.

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