Dynamically Reconfigurable Routing Protocol Design for Underwater Wireless Sensor Network

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***Abstract*— Underwater Wireless Sensor Networks (UWSN) share the common challenges of terrestrial Wireless Sensor Network (WSN), however they are significantly different from terrestrial WSN. Mainly, because acoustic wireless communication is the main physical layer technology in UWSN. Acoustic communication offers longer range, but has limitations due to low speed of sound, high error probability, limited bandwidth capacity, node mobility and 3-dimensional network architecture. Most of the ground based WSN are static, however the UWSN condition keeps on changing due to water current and channel impairment. Therefore the UWSN must be able to dynamically reconfigure itself. The sensor nodes must be able to re-route their communication if the network configuration changes. In this paper we address a fundamental Networking layer issue by developing a dynamically reconfigurable routing protocol. It is a multi-hop datagram routing scheme which will offer reliable underwater wireless communication by dynamically re-routing the data, when network configuration changes.**

***Keywords*— Underwater Wireless Sensor Networks, Dynamically Reconfigurable, Routing Protocol, NS2.**

I. Introduction

Wireless Sensor Network technology has recently emerged as a very powerful technique for many applications. It has the potential to boost economic growth by revolutionizing communication and control in challenging environments. It has evolved as a promising solution for a wide range of applications, enabling wireless sensing, communication and automation as an ultimate real-time solution. UWSN consists of a number of spatially distributed sensor nodes which perform cooperative monitoring by relaying the sensed data from one another through the network to a data sink and further to the base station.

II. Technical Background

Underwater communication systems today mostly use acoustic technology. Complementary communication techniques, such as optical [1,2] and radio-frequency [3], or even electrostatic communication [4], have been proposed for short-range links (typically 1-10m), where their very high bandwidth (MHz or more) can be exploited. These signals attenuate very rapidly within a few metres (radio) or tens of metres (optical), requiring either high-power or large antennae [5].

Acoustic communication offers longer range, but has limitations due to high and variable propagation delays, high bit error rates, limited bandwidth capacity and temporary losses of connectivity caused by multipath, fading and asymmetric links [6][7]. Together these constraints result in a communication channel of poor quality and high latency, thus combining the worst aspects of terrestrial mobile and satellite radio channels into a communication medium of extreme difficulty [5]. Hence the Networking protocols developed for WSNs are not applicable for UWSNs. A typical architecture of UWSN is shown in Figure 1 [8].

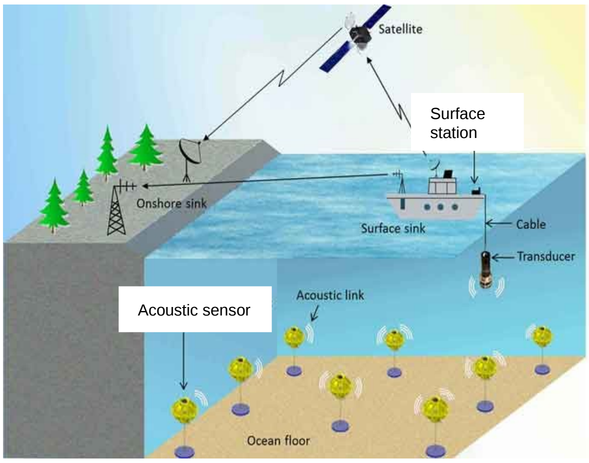

Figure 1: Typical architecture of UWSN [8]

For acoustic wave carriers, apparently the key challenges are in communication and networking [9]. For electromagnetic radio wave carriers, the main shortcoming stays with the high absorption of EM waves in water, especially in seawater. Optical carriers will remain to be used for some special applications and the major hurdle is that optical communication in water is largely constrained by environments [9].

III. RELATED WORK

In the last few years, much research work has been done on the Networking layer of UWSNs. There are a number of routing protocols being developed. Some of them claim to consider changing network configuration in future work. The flooding based routing approaches for UWSN (such as HH-VBF [10], FBR [11], DBR [12], H^2-DAB [13], SBR-DLP [14] etc) are simple at computation and have acceptable end-to-end delay, low processing overhead and can be utilized for delay sensitive applications [15]. However, the energy consumption in duplicate transmission, congestion and channel sharing remains a problem. This has been tried to overcome by some contention based approaches to some extent. However the existence of VOID regions (a region which is created due to node movement or failure and is not covered by any other node) and changing network configuration limits this approach. Some of flooding based approaches involve localization, another energy overhead, as the network configuration is constantly changing with water current. Hence localization is an issue in itself for UWSNs.

The protocols utilizing multi-path transmission (such as MVSA [16] and RRA [17] etc) compared to flooding based approaches offers acceptable reliability, energy efficiency, low end-to-end delays, less congestion and interference but more computation involved in maintaining more paths [15]. Therefore efficient solutions are needed to avoid repetitive transmission. In addition the changing network configuration has been completely ignored and this will cause loss of connectivity in sparse network.

The clustering based protocols (such as DUCS [18], Pressure Routing [19] and DCB [20] etc) are complex in terms of processing overhead due to node mobility and re-clustering. An efficient routine mechanism for re-clustering can reduce these overheads and this area needs to be worked further in order to avoid loss of connectivity due to changing network configuration.

Adaptive routing [21], localization based scheme seems efficient for static networks. The key idea of this routing scheme is packet priority based network resource allocation. Hence an important packet will be delivered reliably with least end-to-end delay compared to an ordinary packet. However this scheme does not support dynamically reconfigurable network architecture.

IV. THE NEED FOR DYNAMICALLY RECONFIGURABLE ROUTING FOR UWSN

Issues relating to different layers of the network protocol stack are being addressed and solutions proposed. However, research is still in the early stages and requires extensive work to be done before it can reach a mature stage. A number of routing protocols have been developed. But none of the routing schemes offers a dynamically reconfigurable routing solution, capable of overcoming the loss of connectivity due to changing network configuration, which is fundamental for UWSN.

Empirical observations suggest that water current moves at a speed of 3-6km/h in typical underwater condition [22]. Node mobility due to water current can be supportive, if a node comes in transmission range of another node due to movement. But it can be against by creating VOID region, that is if a node moves out of the transmission range of its neighboring node due to water current. In addition node failure, battery failure and channel impairment keeps the network configuration to be changing constantly. This results in loss of connectivity among the nodes and interrupts the usual communication, unlike static WSN. In which a connection once established stays till the node dies.

One possibility can be increasing the node density and try to over come loss of connectivity, however this will not ensure reliable communication at all times. Also UWSN nodes are expensive and this will not be the ideal solution. Hence one of the most important issues to be dealt with while designing a routing protocol is to design an efficient dynamic reconfiguration process in order to overcome the loss of connectivity due to changing network configuration and ensure successful data transmission.

V. DYNAMICALLY RECONFIGURABLE ROUTING PROTOCOL DESIGN

We are developing a routing scheme which will offer reliable underwater wireless communication. It possesses a dynamic reconfiguration strategy within the routing protocol, which will provide optimum alternative paths for successful transmission of data without any interruption.

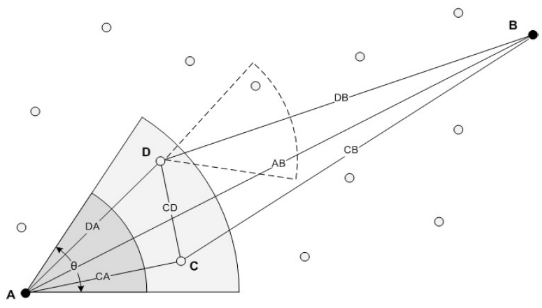

Figure 2: Focused Beam Routing (FBR) [11]

Our protocol design has originated from the idea of Focused Beam Routing Protocol (FBR) [11] and Sector Based Routing with Destination Location Prediction (SBR-DLP) [14]. We have taken into account transmission cone as in FBR as shown in Figure 2, to save energy however we will not be increasing the transmission range to overcome loss of connectivity as in

FBR since it causes huge energy overhead. Our dynamic reconfiguration process will overcome the loss of connectivity.

A. Outline

In our routing protocol design each sensor node intelligently keeps a record of its neighboring nodes without any localization involved. Each sensor node saves energy due to directional antenna transmission. When a data packet is sensed, the node checks its memory if this packet is already transmitted, if not, it is transmitted to the top priority neighboring node. Due to changing network configuration if all neighboring nodes go missing, the data packet follows the backwards path until it reaches a node which can forward the packet successfully. This packet then helps the data Sink to get the missing nodes replaced in the network. Hence successful transmission of data is ensured at all times. As the network configuration keeps on changing, our routing scheme will involve less resource overhead compared to any other algorithm which involves localization and pre-allocation of the routing path during initialization phase.

B. Network Architecture

In our design we divide the subsea into three layers; Sensing field, Communication field and Receiving field as shown in Figure 3. The demarcation of these layers is arbitrary and conceptual. They can overlap for certain application. Although all sensor nodes in the UWSN are capable of sensing data but in the Sensing field we are emphasizing the fact that this layer of UWSN will be least involved in relaying a data packet as being at lowest depth, for example at the seabed. Hence its main task is sensing and forwarding its own data. We propose the Sensing field to be comprised of anchored or mounted, known location based sensor nodes. This layer will also provide the backbone to our network architecture while

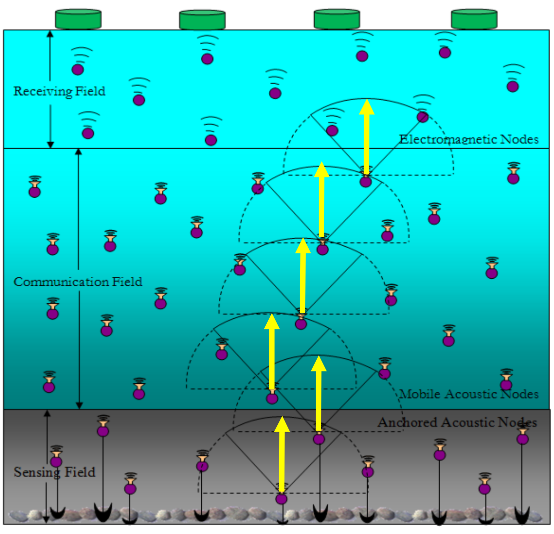

Figure 3: Our Protocol Architecture

mending the VOID region. The exact density and location of these sensor nodes can be optimized for certain application.

The Communication field is the main field (regarding routing) located in the middle of the Sensing and Receiving field. It is comprised of mobile sensor nodes, with constantly changing network configuration. The Receiving field consists of destination sinks and mobile shallow water sensor nodes. We propose electromagnetic sensor nodes for this layer to benefit from high bandwidth of electromagnetic communication in shallow water. However initially we consider all sensor nodes in our network architecture to be acoustic. Our main focus is reliable communication within these layers overcoming the loss of connectivity due to changing network configuration.

In the initialization phase of our routing protocol each node keeps a record of three or more favourite neighbours in a periodic manner by exchanging HELLO packets. Our routing protocol takes advantage of directional acoustic antenna as shown in Figure 3. The directional acoustic antenna and specific hardware determines the relative position of each node with respect to its neighbours by determining the distance, angle of arrival and strength of the signal without any localization facility [23]. Hence the movement and getting out of sight timing of the neighboring nodes can be determined in order to update the favourite neighbours.

The radiation pattern of the directional acoustic antenna of each sensor node should be maximum 180 degree angular in upward direction towards the seatop. Hence for forwarding the data packet, the maximum power should be radiated in upward direction. Because in UWSN normally the sinks are located at the seatop hence the sensed data need to travel from lower layers of the sea to seatop. In this case due to directional antenna, the energy will not be wasted being transmitted in all directions as in omni directional antenna. Hence each sensor node will save energy due to directional transmission.

We have multi-sink architecture in our design due to its known benefits such as energy conservation by shortening the distance a packet has to travel until reaching the data sink. We also emphasize minimum exchange of messages among nodes as more exchange of messages means more energy consumed. Limited battery life is the basic constraint of WSN as well as UWSN.

Our directional antenna transmission cone is bisected by a virtual vector (yellow arrow) from bottom to top at each hop as shown in Figure 3, instead of prioritizing sector based scheme as in SBR-DLP [14] which causes energy overhead due to exchange of initialization messages and predicting destination location. There is no pre-establishment of path from source to sink in our design. Due to high propagation delay in acoustic communication there is a possibility that the best allocated route may change after the next hop. Hence a best forwarding node is selected at each hop to ensure successful data transmission. If an acknowledgement of a successful delivery at each hop is not received then the data packet is re-routed to the second best forwarding node.

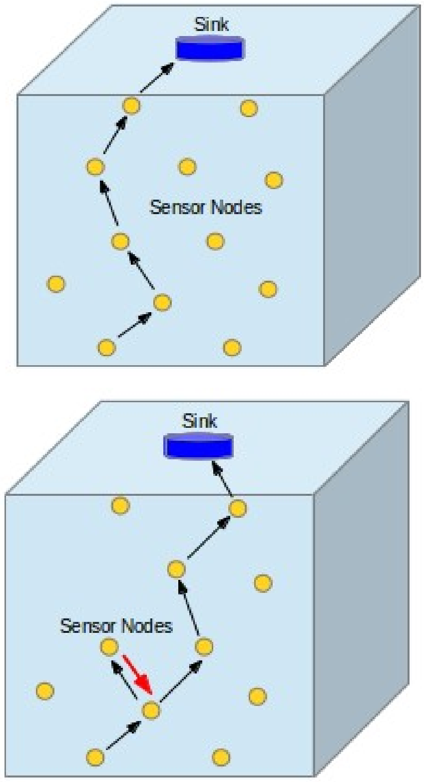

Figure 4: Hop-by-Hop Dynamic Reconfiguration

Due to changing network configuration, each sensor node updates its favourite neighbours periodically, by calculating its relative position (as explained earlier). There is high probability that if a neighboring node goes missing another node will come into range due to water current. However if the last neighboring node goes missing and there is no node to relay data packet further, the data packet follows the backward path. In this case the sensor node will transmit in omni-direction to reach the backward path. This data packet contains the location information of that node (with missing forwarding neighbours). The location information is determined with the help of anchored, known location nodes deployed in the Sensing field. Then this data packet checks hop-by-hop all the way till it finds a node with better connection to other nodes. Finally this new node with better connection with other nodes, forwards the data packet as shown in Figure 4. As soon as the data packet reaches the sink, the node (with missing forwarding neighbours) is located and its missing neighbour nodes are replaced in order to fill the VOID region with replacement nodes. This is done with the help of AUVs (autonomous underwater vehicles). In this way the communication is not interrupted as well as the VOID area is recovered.

The forwarding node at each hop is selected as being less in depth with better connection with other nodes (the remaining battery life will be considered in future in order to maximize the overall life of the UWSN).

In our simulations we are considering a 3D field with random distribution of 100 sensor nodes in a volume of 1000 x 1000 x 500 m^3, with one data source and one sink (initially). Except source and sink all other nodes are mobile at the speed of 1.5 m/s, in horizontal 2-dimensional, X-Y plane. This is the most common mobility pattern in subsea [24]. The transmission rate is set to be one packet per 10 seconds, in order to reduce interference so that each data packet is transmitted far behind the other on the time line. The results of each simulation are averaged over 100 times. The total simulation time for each run is 500 sec. Initially our main simulation parameter is Packet loss rate.

We are taking benefit of the DESERT [25] underwater libraries and NS-Miracle [26] for our simulations in NS2. NS-Miracle enhances the network simulator NS2 with an engine for handling cross-layer messages and, at the same time, for enabling the co-existence of multiple modules within each layer of the protocol stack. In fact, NS-Miracle shows a high modularity and has been designed to simulate nodes whose logical architecture is as close as possible to what would be found on actual devices [25].

DESERT underwater, a set of C++ libraries extends NS-Miracle in order to provide several protocol stacks for underwater networks, as well as their support routines required for the development of new protocols [25]. Our routing protocol simulations are in progress.

VI. Conclusion

While designing a routing protocol, challenging underwater physical layer properties cannot be ignored. There is a serious implication of underwater acoustic communication constraints and changing network configuration due to node mobility. In this paper we have summarized a part of our ongoing research in UWSN which explains the dynamically reconfigurable routing protocol design which provides the optimum alternative paths for successful transmission of data without any interruption and allows reliable communication within limited resources. In our future work, we shall investigate the performance of our architecture by simulating example situations and error conditions. Further we shall compare the performance of our routing scheme with various routing protocols for UWSN.

VII. Acknowledgment

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