DISTRIBUTED PROTOCOL FOR COMMUNICATIONS AMONG UNDERWATER VECHILES

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Abstract – Underwater surveying by swarms of autonomous underwater vehicles presents problems in communication among the robots. These problems involve the bandwidth, power consumption, timing, processing power, and other issues. This paper presents a novel approach to communicate and coordinate effectively among underwater vehicles to accomplish this task successfully. The proposed approach solves issues by reducing the number of hops to conserve power, while reducing computation time and bandwidth, effectively utilizing resources to reduce the load on each node. Finally, the simulation results are presented, in order to prove that the proposed approach improves efficiency and effectiveness in communicating among underwater vehicles.

I. INTRODUCTION

The ocean covers about two-thirds of the earth and has a great effect on the future existence of all human beings. About 37% of the world's population lives within 100 km of the ocean. Oceanic resources are often overlooked compared to land-based resources. We have not fully explored the depths of the ocean and its abundant resources. For example, it is estimated that there are about two trillion tons of manganese nodules on the floor of the Pacific Ocean near the Hawaiian Islands [1]. As another example, only recently have we discovered, by using manned submersibles, that a large amount of carbon dioxide comes from the seafloor and extraordinary groups of organisms live in hydrothermal vent areas. Underwater robots can help us better understand marine and other environmental issues, protect the ocean resources of the earth from pollution, and efficiently utilize them for human welfare. However, a number of complex issues arise due to the unstructured, hazardous undersea environment, making it difficult to travel in the ocean even though today's technologies have allowed humans to land on the moon and robots to travel to Mars.

Autonomous underwater vehicles (AUVs) are unmanned, untethered, self-propelled platforms [2]. AUVs have the potential to revolutionize our access to the oceans and to address the critical problems faced by the marine community such as underwater search/rescue[3], mapping, climate change assessment, underwater inspection, marine habitat monitoring, shallow water mine counter measures [4] and scientific studies in deep ocean areas. Communication is one of the primary requirements for AUVs to solve problems comprehensively. In this paper we will address the communication aspects of autonomous underwater vehicles to perform a task cooperatively. The next section briefly reviews the problems related to underwater communication using acoustic, optical, fibre line and other communication techniques between multiple AUVs. Section III describes about experiment overview, which led to identify the communication range of the modules. Section IV describes about the brute force approach and issues related to this approach. Section V describes our proposed approach and its capabilities in order to improve efficiency and its effectiveness in communication among multiple AUVs. Section VI describes the simulation results and future research.

II. BACKGROUND

Being able to achieve reliable communication is an important open area of research to robotics as well as other technology areas. In particularly, we are concentrating communication among robots in underwater. The nature of the ocean environment and its vast size and depth has lead to the development of sophisticated equipment and techniques for scientific exploration. A wide variety of systems and vehicles have been developed to operate either within the

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shallow continental shelf region or in deep oceans. The traditional method to communicate with the sensor arrays on these underwater vehicles is to use an umbilical from a surface support ship, but this restricts the moverability of the device and ultimately limits the depth to which the system can operate. This has lead to several wireless communication techniques to allow the systems full freedom of movement within the ocean. Wireless information transmission through the ocean is one of the enabling technologies for the development of future ocean-observation systems, whose applications include gathering of scientific data, pollution control, climate recording, detection of objects on the ocean floor, and transmission of images from remote sites.
Implicitly, wireless signal transmission is crucial for control of autonomous vehicles which will serve as mobile nodes in the future information networks of distributed underwater sensors

Present underwater communication systems involve the transmission of information using either acoustic or optical techniques. Optical systems are generally limited to extremely short distances because of backscatter and absorption. Acoustic systems are the most versatile and widely used technique. Both optical and acoustic systems, however, are unable to penetrate behind an object and suffer from shadow zones. In shallow water, the use of acoustic techniques can be severely affected by multi-path propagation in water due to reflection and refraction. The comparatively slow speed of acoustic propagation in water, of the order of 1500m/s, is a limiting factor in terms of transmission data rates. Accoustic communication are governed by three factors: limited bandwidth, timevarying multipath propagation, and low speed of sound underwater. Together, these factors result in communication channel of poor quality and high latency. All these factors lead to choosing some alternative technology to communicate effectively between the AUVs. Researchers have attempted to address these issues. A few have tried to use fiber-optic cables to implement underwater communication, which proved to be expensive, requiring high maintenance and were prone to fiber-optic cable damage. Looking in to all these factors we considered radio modems for communication.

The RF and microwave group of Liver Pool John Moores University has, for the first time, been successful in transmitting high frequency electromagnetic waves through sea water enabling data and images to be transmitted at rates of upto1Mbits/s over distances in excess of 100m. The EM wave propagation system can complement or replace the present acoustic systems to provide safe communications between ships, submersibles and two-way diver to diver communications. The EM wave system can also be used for sensor systems in the oil & gas industry, range finding and anti-collision navigation of sub-sea vehicles, sea pollution monitoring and fish detection. A special feature of EM wave propagation is the large bandwidth by using high frequency (>1MHz) which allows transmission of video images in real time[5].

Autonomous Control Engineering Center at University of Texas at San Antonio has, has been using XBee Pro radio modem modules for communications among land based vehicles, and is experimenting with using these modules for communication underwater.

III. Experiment Overview

An experiment using XBee Pro modules and omni directional antennas showed that underwater communications was possible between two robots apart 25’ and 9’ deep [6]. The XBee Pro modules are 100mW units that use the 2.4GHz radio frequency for communications. The problem with this is that water readily absorbs radio frequencies around the 2.4 GHz region, which is why microwave cooking units operate at 2.45GHz. Therefore experiments using this frequency range will show the worst than typical scenario. Research has been progressed with better results, implemented with respective to the increase in depth and distance between the robots. In this experiment antennas were vertically separated as much as 20 feet with successful communication in a saltwater diving pool.

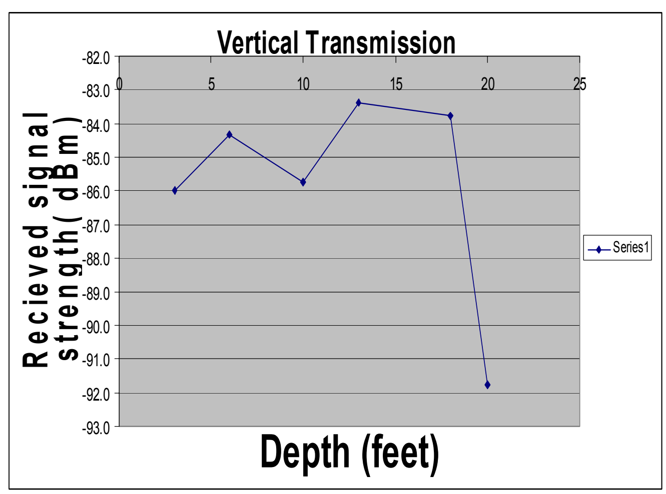

Fig1. Results from experiment in underwater

IV. Different methods of Communications Using Zigbee Radio Modems

In this paper, two different types of underwater communication using Zigbee radio modems for AUV are discussed. One of the approaches is brute force approach. Let us consider the following scenario from Fig.2.

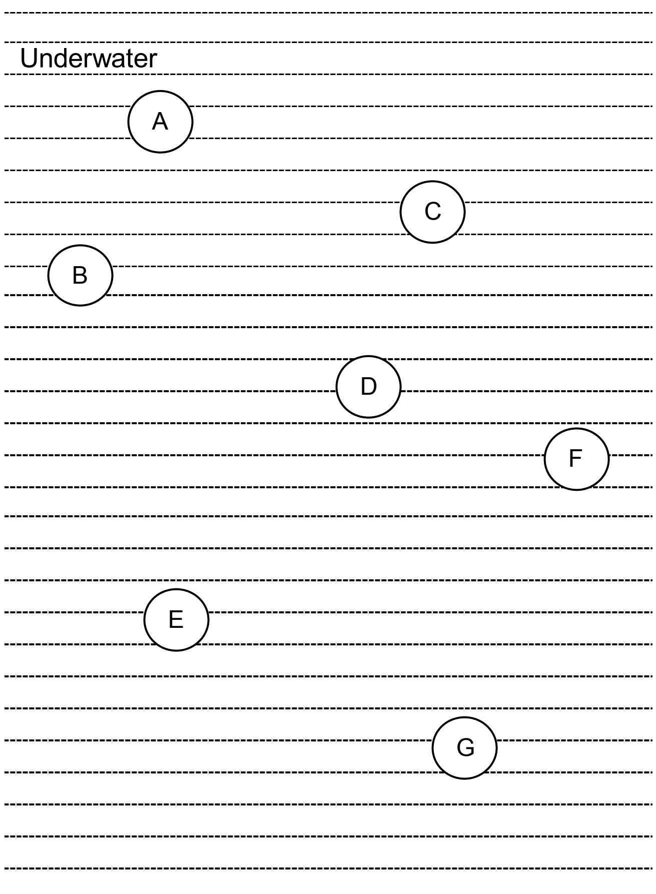

Fig.2Brute force approach

In this case, let us consider small circles representing nodes that are present in AUVs. We need to communicate among AUVs to solve a problem. A node needs to send some information to G node. In the brute force approach only one master is allowed (in this case A is the master). The master allows one packet of information to circulate at any time between all the other nodes. Every node has a unique identification number, and every packet has a unique identification number corresponding to its destination (In this case the packet identification number is destination G identification number). Each time that a node receives a packet it first verifies that its identification number matches the packet identification number. If so, it stores the packet in the memory and in turn broadcasts an acknowledgement else it transmits the packet to neighbouring nodes. If the node receives the same packet from another node simultaneously, it automatically ignores the second packet, and after certain period of time, it accepts the next packet.

Example for Brute force Approach:

1) A node broadcasts packets to its neighbours (B&C).

2) B and C receive packet from A and after the verification process is completed, based on the result, it either stores in memory or send packets to neighbours (in this B and C send packets to D).

3) D will accept only one packet either from B or C and ignores the other packet. After the verification, process is completed based on the result it either stores in memory or send packets to E and F.

4) E and F receives packet from D and after process of the verification is completed, based on the result it either stores in memory or send packets to G.

5) G will accept only one packet either from E or F and ignores the other packet. After verification process is completed, based on the result it either stores in memory and the acknowledgment is sent back to E or F.

6) Repeat the steps until all the packets are transmitted to the respective destinations.

Finally the packet reaches destination node G. This approach requires at least 8 hops to receive a packet from source (A) to destination (G). As the number of hops increases, the time delay increases and power consumption also increases. Message collision is the most important factor to be considered in this approach, because it leads to packet loss. This is an issue because retrieving the packet again utilizes lot of resources. The other practical issues of this approach are load on the node, utilization of resources like memory, battery and bandwidth are high. Taking all these issues it is concluded that, the proposed method helps to solve the issues and improve efficiency of the approach and its effectiveness in communication between autonomous underwater vehicles.

V. PROPOSED APPROACH

In the proposed approach we assume the position of each robot is known by existing localization techniques [7]-[8]. The position of robot is given in the form of (X-axis, Y-axis, and Z-axis). Consider the scenario in Fig. 5. In this case we consider these small circles representing nodes that are present in AUVs. We need to communicate among AUVs. A node should send some information to G node to establish communication. In this approach position of the robot is also included with the acknowledgment. Every node has also a unique identification number, and every packet has unique identification number corresponding to its destination (In this case the packet identification number is destination G identification number). Each time a node receives a packet, it first verifies that its identification number matches the packet identification number. If so it stores the packet in the memory and in turn broadcasts an acknowledgement, else transmits the packet to neighbouring nodes. In the proposed approach master can be switched in case of failure in the system (in this case A is the master node).

Algorithm for proposed Approach:

1) Determine the position of all the existing nodes using the broadcasting method. In broadcasting method the master node send packets to all other the nodes. It receives back the acknowledgment from other nodes with their respective positions.

2) The shortest paths are calculated between the master node and destination node. The shortest paths refer to that with the fewer hops from the master node to the destination node.

3) If there are two or more shortest paths, the most reliable path is chosen from the shortest paths.

4) Reliable path is calculated based on the physical distances between the nodes.

5) Select the largest physical hop distance from each shortest path. The largest physical hop is calculated using the following distance formula.

Distance Formula= $\sqrt{(x_a - x_b)^\wedge 2 + (y_a - y_b)^\wedge 2 + (z_a - z_b)^\wedge 2}$

6) When comparing the largest hops from each shortest path, the smallest of largest hop is chosen.
7) Reliable path is decided based on the result of step

8) Each time a node acknowledge to master node it also updates its position. Based on this, the master node verifies if there is any change in the position of the nodes.

9) If there is any change in the position of nodes, go to step 1.

10) If there is no change in the position of the nodes use the existing path to send all the packets.

Finally, the packet reaches destination node G. This approach requires at least 4 hops to receive a packet from source (A) to destination (G). As the number of hops decrease, the time delay and power consumption also decrease. The result shows that the proposed approach reduces 50% of resource utilization. This proposed approach has a lower chance of message collision compared to the brute force approach. If there is any chance of message collision, it will utilize only 50% resources to retrieve the packet back to the node. All of the issues of brute force approach are discussed and solved by coming up with a new method to improve practicality of this approach and its effectiveness in communication between autonomous underwater vehicles.

VI. RESULTS

From Fig.1, we can conclude that our communication module can work without significant packet loss, within 20 feet in any direction from source robot. Taking in consideration these results, simulations are done in order to prove our proposed algorithm is more effective in communication, requiring usage of fewer resources and addressing other practical issues like load on each node, time delay etc. The general scenario of our simulation shows a three dimension view. We have considered pool size of 50 feet in length (X-axis), 50 feet in breadth (Y-axis) and 30 feet depth (Z-axis). Eight robots were simulated within this 75000 cubic foot pool. One of the eight robots acted as source of messages destined for one of the other seven robots chosen at random.

Fig.3 shows the initial stage results of the brute force approach. All nodes within communication range will receive the packet. Dotted lines represent this first hop. The four robots indicated at the end of these lines are in range of communication with the source robot, and the remaining three robots are out of direct communication range of the source. At this point, all four robots that received the message pass it along to all of the robots within range, including the robots that have already received the message. The main disadvantage of this brute force approach is shown in this Fig. 3. The nodes which had already received the initial message continue to process the message redundantly, so utilization of resources is excessively high. Fig.4 depicts the final stage of the brute force approach. In this approach, the destination node receives the same information five times from five different nodes that were reached in the first hop. Once the first packet is received, the receiving node compares the received packet with previous packets. If it is a duplicate packet, it is ignored to save time and resources.

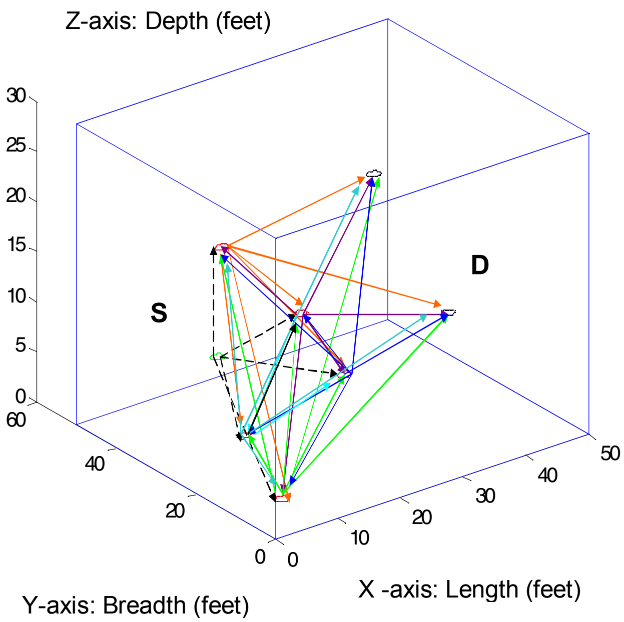

Fig.3 Initial stage of brute force approach

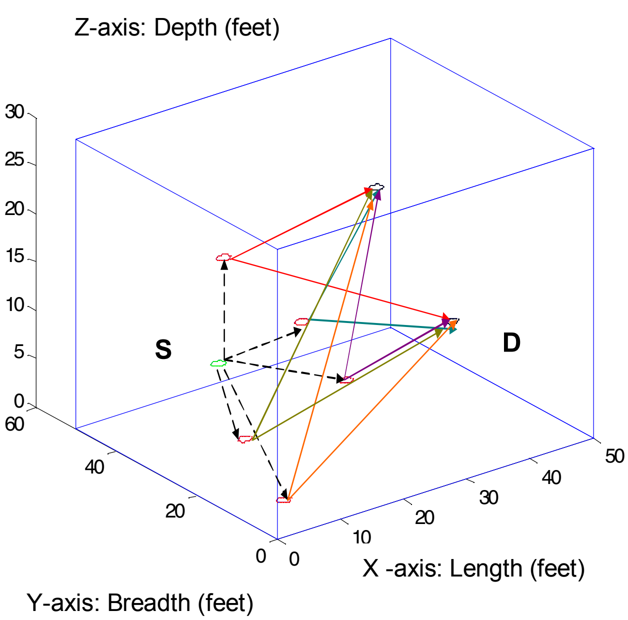

Fig.4 Final stage brute force approach

The proposed algorithm results are shown in Fig 5. The dotted line represents these that are in range of communication with the source and the solid line represents out of communication range with the source. Let us consider the source is robot 1 and destination is robot7 or robot 2 as shown in Fig.6. The path is calculated based on the proposed algorithm. Path is 1-5-2 if destination is node 2 or the path is 1-4-7 if the destination is node 7. The destination node receives the packet from source in an efficient way for communication in order to accomplish the task successfully.

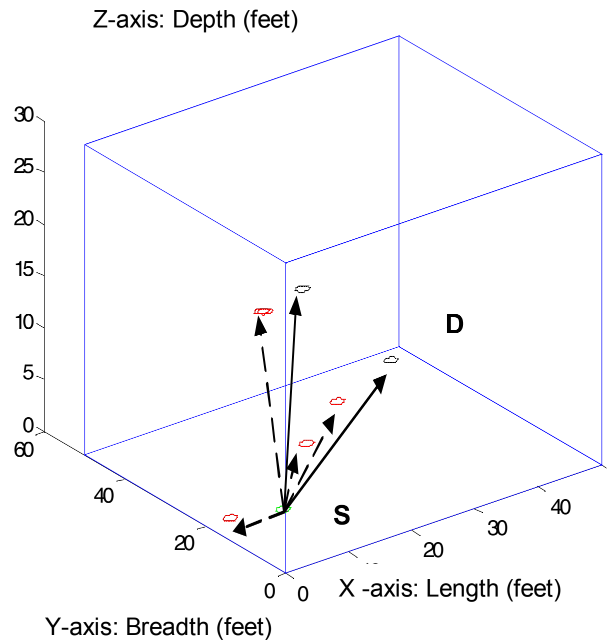

Fig.5: Proposed approach final stage

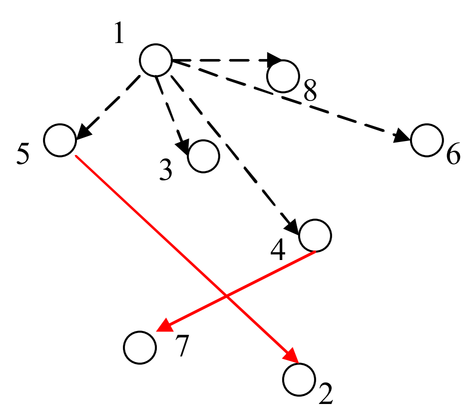

Fig.6 Simplified version of proposed approach

From Fig.6 Distances from source (robot1) to all other robots are calculated as below

Robot (1)ID	2	3	4	5	6	7	8
Distance (feet)	21.5	12.2	19	8.9	18.8	20.4	7.08

Table.1 Distances from robot1 to other robots

From Table.1 we found out that robots with ID 3, 4, 5, 6, 8 are in range of robot 1 for communication and robots IDs 2, 7 are out of range of communication from robot ID 1. Distances are again calculated from robot ids 3, 4, 5, 6, 8 to robot IDs 2 and 7 as below:

Robot Id	3	4	5	6	8
2	14.4	22.5	13.754	18.64	27.04
7	11.7	6.4	16.0	6.9	22.84

Table.2 Distances from robot IDs within the range of communication with the source to out range of communication with the source. Paths are calculated based on these results.

VII. CONCLUSION

We have investigated problems in a brute force approach and provided a novel approach to effectively communicate among a small fleet of AUVs to solve a problem cooperatively. With these results, we can conclude that the proposed approach has achieved effectiveness in communication far above and beyond the brute force method. Future research should continue to increase the range of communication of modules used in order to achieve more robust and reliable communication.

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