Open access • Proceedings Article • DOI:10.1109/SYSTEMS.2008.4519035

Communications for Underwater Robotics Research Platforms — Source link

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Published on: 07 Apr 2008 - IEEE Systems Conference

Topics: Underwater robotics, Intervention AUV, Underwater acoustic communication, Underwater acoustic positioning system and Remotely operated underwater vehicle

SysCon 2008 – IEEE International Systems Confer nce
Montreal, Canada, April 7–10, 2008

COMMUNICATIONS FOR UNDERWATER ROBOTICS RESEARCH PLATFORMS

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Abstract - This paper presents a distributed protocol for communication among autonomous underwater vehicles. It is a complementary approach for coordination between the autonomous underwater vehicles. This paper mainly describes different methods for underwater communication. One of the methods is brute force approach in which messages are broadcasted to all the communication nodes, which in turn will broadcast the acknowledgement. Issues relating to this brute force approach are time delay, number of hops, power consumption, message collision and other practical issues. These issues are discussed and solved by proposing a new method to improve efficiency of this proposed approach and its effectiveness in communication among autonomous underwater vehicles.

I. INTRODUCTION

Due to extreme difficulty in gathering sub aquatic observations, very little is known about the oceans and their inhabitants. We do know, however that the oceans are an extremely complex and an equally important part of the world in which we live. They cover the majority of the planet's surface, influence our climate, host countless species of plants and animals, and are home to important geological processes. Since they are notoriously difficult to study, they present one of the final frontiers for exploration. Since the underwater environment is very dark and musky much of its biology and geology must be studied at very close range. At greater distances, even powerful lights fail to illuminate a scene sufficiently. The goal of our research is to improve underwater robot technology in order to enable more scientific exploration of the oceans.

Autonomous underwater vehicles (AUVs) are unmanned, untethered, self-propelled platforms [1]. 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 [2], mapping, climate change assessment, underwater inspection, marine habitat monitoring, shallow water mine counter measures [3] and scientific studies in deep ocean areas. Recent trends in AUV technology are moving towards reducing the vehicle size and improving its deployability to reduce the operational costs. This research aids future operations that involve a fleet of small AUVs become financially and technologically feasible. This work can be integrated with the work of other AUVs researchers; as a result of which the underwater robots will enable a new class of AUVs, which are capable of gathering scientific observations without direct interaction of human operators and other applications.

Localization, navigation, and communication are three primary requirements for AUVs. In getting AUVs to solve problems comprehensively, a key issue is communication. 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 acoustic communication and reasons for choosing Zigbee radio modems for communication between multiple AUVs. Section III describes different methods for communication using Zigbee radio modems. Section IV describes our approach in designing the new method in order to improve efficiency of this proposed approach and its effectiveness in communication among multiple AUVs.

II. BACKGROUND

Underwater communication can be implemented in numerous ways including acoustic propagation [4], fiber-optic communication, and radio modems. Acoustic propagation faces a lot of problems compared to radio modems. These problems are mainly due to very limited bandwidth, large signal propagation time and overload on the receiving antenna by local transmit power levels (Near and Far problem) [5]. The limited bandwidth implies that the use of multi-channels techniques is very limited. The near and far problem occurs when an acoustic unit may not transmit and receive at the same time because of local transmit power levels. Large propagation delays involved in acoustic propagation are in the range of seconds. 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[6], 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 radio modems chosen are Zigbee modules. Zigbee is a low-power [7] wireless communication technology and an international standard protocol for the next- generation wireless networking. It reduces the data size and allows for lower-cost network construction with simplified protocol and limited functionality. Zigbee uses the [8] MAC layers and PHY layers defined by IEEE® 802.15.4, which is the shortest- distance wireless communication standard for 2.4GHz. The benefits of Zigbee are that it supports three different topologies: star, mesh, cluster-tree networks, robustness, simplicity, low-power consumption and mesh networking. [9] 802.15.4 provides a robust foundation for Zigbee, ensuring a reliable solution in noisy environments. Features such as channel assessment and channel selection help the device to pick the best possible channel, avoiding other wireless networks such as Wi-Fi. Message acknowledgment helps to ensure that the data is delivered to its destination. The ability to cover large areas using routers is one of key features of Zigbee networks and helps to differentiate it from other technologies [10]. Mesh networking can extend the range through routing and it also has self healing capability that increases reliability of the network by re-routing a message in case of node failure. Finally, multiple levels of security ensure that the network and data remain intact and secure.

The problem, however, with underwater communications using radio is radio doesn't work very well, if at all, underwater. To achieve a distributed protocol network [11] for underwater communication, we need to find out the range of each module in underwater. So the following experiments are conducted. We tested our Zigbee modules in a 9 foot deep swimming pool to examine the affect of attenuation on range between transmitter (base) and receiver (remote). Also depth of base and remote were considered. For every combination of range and depth, received signal strength (RSS) and data packet success rate were recorded. Each time 15 packets of information is sent from base to the remote. Base, remote and the experimental setup is shown in Fig. 1.

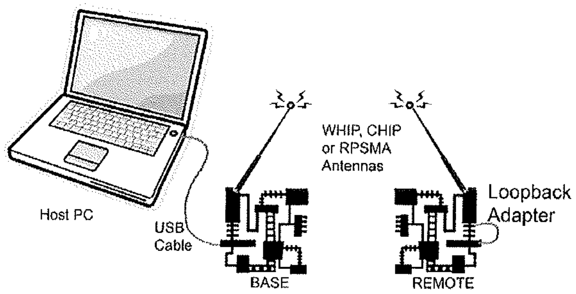

Fig. 1 Experimental Setup

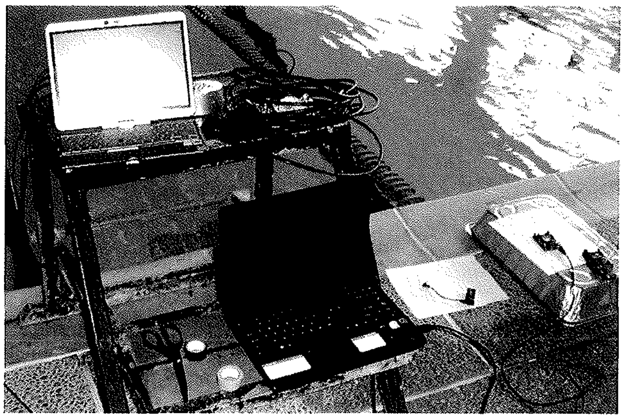

Fig. 2 Real-time experiment setup

In the first experiment both the base and remote modules were placed next to each other on the waters edge and shielded cable was used to suspend the antennas under the water. Each time 15 packets were sent from base to the remote at different depths and different distances between base and remote. Hit rate was always 100%. In this case hit rate defines as follows

$$\text{Hit rate} = \frac{\text{Total number of correct packets returned from Remote to Base}}{\text{Total number of packets transmitted from Base to Remote}}$$

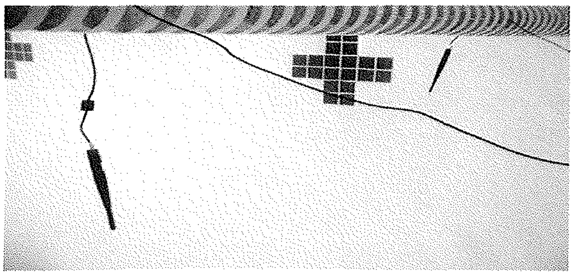

Fig.3 Arrangements of antennas in swimming pool

From this experiment, the received signal strength is obtained at different depths and different distances between base and remote. Observing the received signal strengths at different levels at certain stage, we can approximate the distance between the modules. This approximation helps us to find out the approximate distance between AUVs and acts as a secondary localization system. Results of the experiment are shown in Fig. 4.

From Fig. 4 we can analyze that at 7ft depth, when the distance between modules is 13ft and modules the received signal strength is -68dBm (dBm is a standard for measuring levels of power in relation to a 1milliwatt reference signal) At 9ft depth, when the distance between modules is 13ft and unshielded with aluminum foils the received signal strength is -63dBm. Actually the received signal strength should decreases, but in this case it is increasing. Analysis of received signal strength appeared too optimistic and it is considered that the modules themselves, being unshielded, may have emitted enough radio waves to communicate above the water. So the modules should always be shielded to avoid radiation and reduce the affect of attenuation on the signal

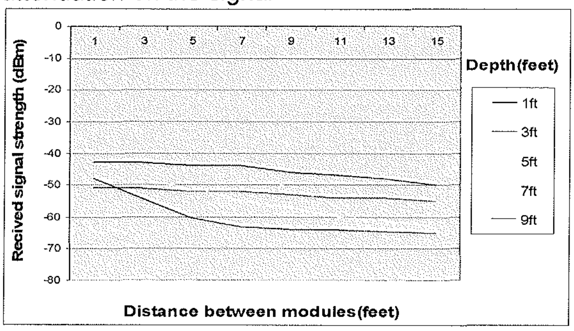

Fig. 4 Results from experiment 1

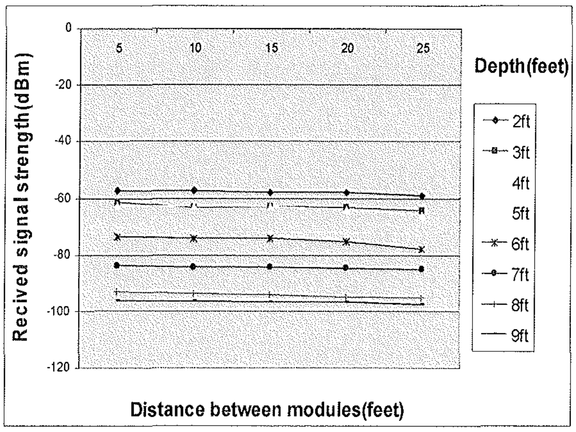

Fig.5 Results from experiment 2

The experiment was the repeated, ensuring that the modules were shielded with aluminium foil. Each time 15 packets are sent from base to the remote at different depths and different distances between base and remote. Hit rate was always 100%. Results of this experiment are shown in Fig. 5. From Fig. 5 we can infer that received signal strength decreases as the depth and distance between base and remote increases. Combining these two experiments these results were plotted in Fig.6 comparing these two experiments, it can be inferred that the received signal strength did decrease once all; the equipment above water was shielded. The experimental resulted in finding out the range of modules and to achieve a distributed protocol network for underwater communication. Once the distributed protocol network is achieved, our next goal is to identify different methods of communication using Zigbee radio modems in order to solve problem comprehensively.

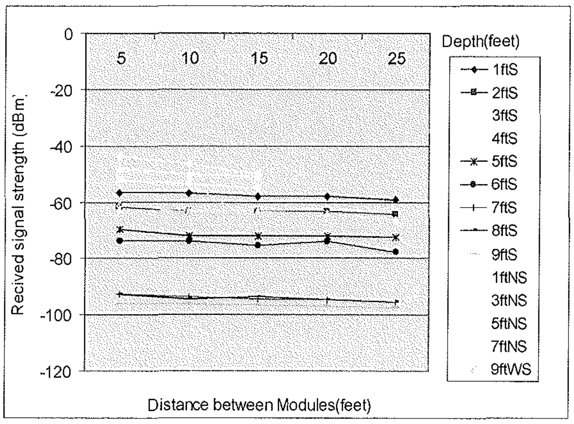

Fig. 6 Comparison between experiment 1 and experiment 2(NS=unshielded, S=shielded).

III 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.7.

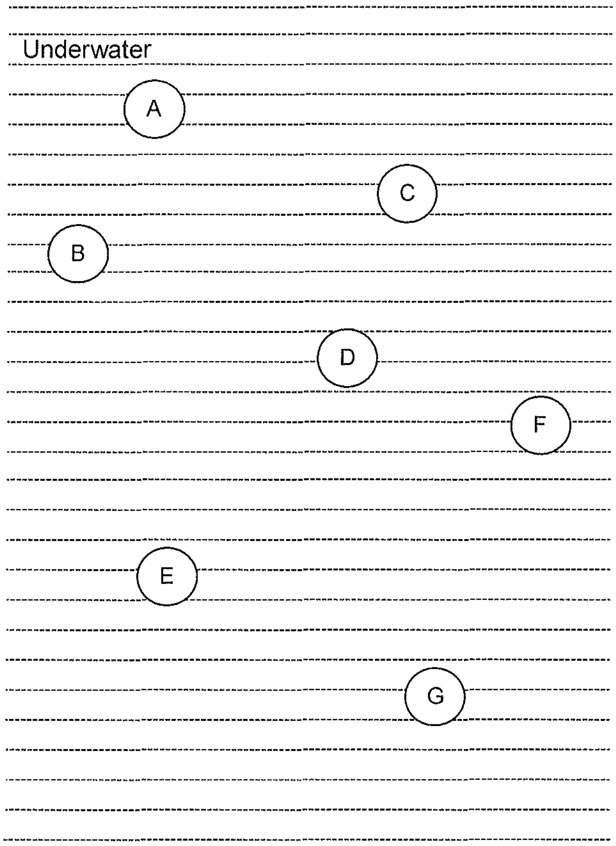

Fig. 7 Brute force approach

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.

IV. PROPOSED APPROACH

In the proposed approach we assume the position of each robot is known by existing localization techniques [13] - [14]. 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 6.

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.

V CONCLUSION

In this paper, we have investigated the problems related to underwater acoustic communication, fiber-optic underwater communication and provided an innovative solution of using radio modems and developing a distributed protocol for underwater communication. We also have investigated the problems in different methods of communications using Zigbee modems and provided a novel approach to effectively communicating among the small fleet of AUVs to solve a problem cooperatively. To the best of our knowledge, there has been few directed research with regards to the usage of Zigbee radio modems and the development of distributed protocol for underwater communication. The proposed approach is very generic in nature and can be applied to any type of radio modems.

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