CDMA-BASED MULTI-DOMAIN COMMUNICATIONS NETWORK FOR MARINE ROBOTS

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ABSTRACT

This paper reports on a cross-domain communication system for marine robots based on code-division multiple access (CDMA). The underwater communications channel is a difficult transmission medium due to its link quality variability which depends on location and the application. It also depends on environmental parameters which can vary temporally from hours to days to months to season. Understanding the channel characteristics for data transmission is essential to the development and evaluation of existing or new MAC and Routing Level protocols which better utilize the limited resources within this unpredictable channel. CDMA is the most promising physical layer and multiple access technique for underwater acoustic sensor networks because it: i) is robust to frequency selective fading, ii) compensates for multi-path effects at the receiver, and iii) allows receivers to distinguish among signals simultaneously transmitted by multiple devices. For these reasons, CDMA increases channel re-use and reduces packet retransmissions, which results in decreased energy consumption and increased network throughput. Development of a framework for autonomous co-ordination and networking of marine robot teams from extended ranges to transmit images/information from underwater to above water is proposed using CDMA which is a complete stack of communications protocol from the physical to the application layer for marine robots that spans multiple domains, i.e. under, on and above water. Simulation of the proposed network was performed using network simulator-3 (NS-3). The proposed protocol edge CDMA properties provide multiple access to the limited underwater bandwidth whereas previous reported work only considered CDMA for the physical layer. Simulations show the proposed protocol outperforms existing underwater acoustic network protocols.

CCS CONCEPTS

• **Networks** → Cross-layer protocols; Network reliability; • **Security and privacy** → Security protocols; • **Computer systems organization** → Robotics.

KEYWORDS

UWSN, Marine Robotics, NS-3, MATLAB, Autonomy, Multi-robot Collaboration - UUV, USV & UAV, Autonomous Mission-planning, CDMA

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1 INTRODUCTION

The underwater acoustic channel is a difficult medium due to its spatial-temporal variability. Before deploying robots underwater, one should know the channel performance as a function of local sound velocity profile at the source and receiver depths, seabed cover (e.g. sand, mud, silt, etc.) and bathymetry.

This is important in the uncertain underwater environment. Underwater acoustic sensor networks (UWASNs) [5] can consist of sensors on unmanned underwater vehicles (UUV) and unmanned surface vehicles (USV) which collaborate with above-water robots like unmanned aerial vehicles (UAV) to perform, for example, collaborative monitoring tasks. As these multi-domain vehicles collaborate, they must communicate (Figure 1).

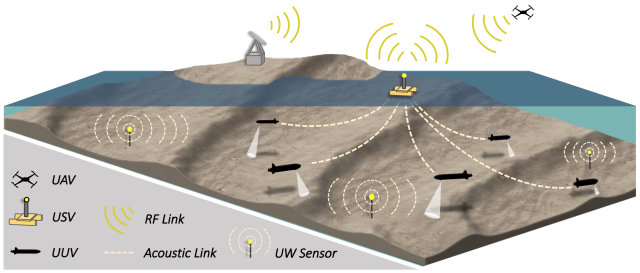

Figure 1: Robotic multi-vehicle collaboration - above and below water

The contributions of this paper are as follows: 1. a novel CDMA-based user datagram protocol (UDP) underwater protocol, UWCDMA, for environments affected by multi-path and integrates underwater acoustic channel characteristics towards more accurate predictions; 2. a submerged network with nodes that can be stationary underwater sensors or mobile UUVs which transmit to mobile USV nodes which further relay above-water to an UAV node, and 3. a multi-domain heterogeneous marine robot collaboration network validated in simulation.

2 BACKGROUND

The motivation of this paper follows the concept of [1] where 7-UUVs, 2-USVs, and 1-UAV collaboratively communicate underwater

information using time division multiple access for under, on and above water. Proposed, is to use CDMA instead so the full channel bandwidth is simultaneously used for multiple signals. This can be achieved with a pre-assigned unique code to each node to extract its signal component from the larger signal.

2.1 Related Work

There are only a few contributions that address CDMA schemes, and at the physical layer only, for frequency selective fading channels. In [4], a MAC protocol was proposed for an UW-ASN. This was a transmitter-based CDMA scheme for deep water (> 100 m) communications which is not affected by multi-path. There was little discussion on the use of this in shallow waters which would be more severely impacted by multi-path.

2.2 Methodology

There are developments in underwater acoustic network (UAN) simulators [2] and emulators [6]. Among them, NS-3, is a good candidate for the work here given features like cross-layer protocol development and tools to design the network topology. [6] proposes a physical layer module which focuses on communications with external devices (e.g. an underwater modem) to complete message transfers between the simulated MAC layer and real-time modems used.

The NS-3 core module and the CDMA module was used to design UWCDMA network, which uses Bellhop and the proposed UW Ray Tracing Toolbox to calculate transmission loss. This is further integrated with NS-3's Thorp Propagation Model [3] which uses environmental propagation information which is passed to the Bellhop Propagation Model. This framework uses conventional on air-CDMA for communication between the master node and UUV [3].

Simulations were performed for an autonomous ocean observation network with 15 nodes: 2-UUV, 1-USV, 1-UUV ,1-master (on-board the USV) and 10-submerged stationary nodes.

3 SIMULATION RESULTS

The proposed protocol's performance was compared against existing the UW-GOAL protocol [7] for the 15-node network example (Figure 2). The simulation results appear promising and implementation is underway to test this at-sea.

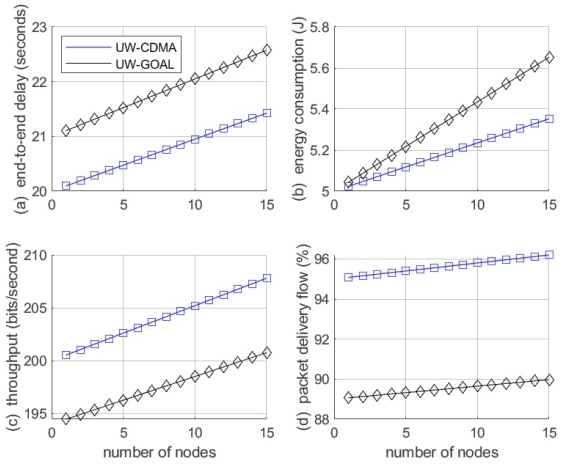

Figure 2: Measures of performance for the UW-CDMA vs number of nodes relative to UW-GOAL: (a) end-to-end delay is 1 second less; (b) energy consumption is 0.2 J less at 15 nodes; (c) the throughput is 5 bits / second higher, and (d) the packet delivery flow is 6% greater overall.

4 CONCLUSION

The simulation results are encouraging for the proposed CDMA protocol. Its implementation is underway however, merging under, on, and above water models is expected to increase the complexity.

5 ACKNOWLEDGMENTS

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