An SDN Architecture for Under Water Search and Surveillance

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***Abstract*—Underwater Wireless Networking (UWN) schemes and applications have been attracting considerable interest with both industry and the research community. The nature of water, as a carrier medium, imposes very significant constraints on the both the characteristics and information carrying capacity of underwater communication channels. Currently, acoustic and optical are the two main physical platform/channel choices. Acoustics offers relative simplicity but low data rates. Optical has a considerable bandwidth advantage, but is much more complex to implement, exploit and manage. Leveraging both technologies enables exploitation of their complementarities and synergies. A Software Defined Networking architecture, which separates the control and data planes, enables full exploitation of this acousto-optic combination. In this configuration, the longer-ranged acoustic channel serves as the control plane, allowing the controller to issue mobility and network related commands to distant AUVs, whilst the shorter range (but higher throughput) optical channel serves as the data plane, thereby allowing for fast transfer of data. This paper presents such a system, employing the NATO approved JANUS underwater communications standard for the control channel.**

I. Introduction

As a result of increasing demands from the off shore industry, Underwater Wireless Networking (UWN) has attracted special focus in recent wireless communication studies. Owing to the physical characteristics of the underwater channel, various Electro-Magnetic (EM), optical, and acoustic communication technologies have been applied to UWN for different communication ranges [8]. EM waves have wide frequency bands and fast propagation speed, but the attenuating nature of sea water severely constrains the communication range. Underwater optical communication has advantages in bandwidth and propagating speed, yet its communication range is limited by the absorption and backscatter in water. Acoustic waves have the longest transmission range in underwater environments, but encounter challenges in the temporally and spatially varying underwater acoustic channel. Long propagation delays, bandwidth constraints and high error rates are frequently cited challenges. Acoustic and optical carriers are the two modes of communication most seriously considered by researchers, with the bulk of attention paid to acoustics because of its relative simplicity - it is treated the same as EM in the air, except for long propagation delays. Optics, on the other hand, is much more complicated. Aside from its short underwater communication range, optical PHY links are typically line of sight and usually uni-directional, requiring relative localization among communicating nodes. At the same time, these properties give optics the potential for covertness, since a finely aligned optical beam can help elude detection or interception. These different characteristics and propagation properties provide some very interesting trade off scenarios, and motivate the combination of different techniques to create a hybrid approach [6].

Software defined networking (SDN) is a relatively new networking paradigm where high level abstractions enable decoupling the data plane (where actual data is transmitted), from the control plane (where meta-data related to network functionality is transmitted). This is done by utilizing a centralized network controller (the Open Flow (OF) Controller) that has a dynamic, up-to-date view of the network and which defines network behavior among all the nodes based on user demands. The work by [7] gives a comprehensive survey of ongoing research in the SDN area.

The use of the SDN centralized control for UW networking is motivated by the complex nature of the tradeoffs between different constraints that makes a dynamic distributed optimization (integrating the controls in the data plane) very difficult to achieve. We thus define an under water SDN architecture, complete with a central network controller, that principally handles routing and movement decisions for each Autonomous Underwater Vehicle (AUV). The control plane is separated from the data plane by using a separate control channel. In this paper we propose to use JANUS, the NATO defined standard, for the control channel signalling.

II. Related work

Much work has been carried out on various aspects of underwater acoustic networks, such as the acoustic channel model, simulation software, protocol design, and localization algorithms. The OCEAN-TUNE Long Island Sound testbed consists of an on shore control center, off shore surface nodes and bottom nodes with sensors, which can help collecting oceanographic data, as well as providing the UWN research community flexible and ubiquitous access to field experiment resources [14]. The concept of Software Defined Networking (SDN) has been recently introduced for next generation underwater communication networks [1]. Hardware prototypes for software-defined underwater acoustic modems, e.g. SEANet [2], have also been implemented.

III. Design

Our under-water SDN system is a network of mobile sensor nodes in the form of AUVs mainly confined to a specific area in the ocean where they will conduct their search and surveillance mission. The basic architecture is depicted in Fig 1. Close to the Ocean floor are the AUVs, that are networked together to form a mesh network feeding to an Unmanned underwater Support Vehicle (USV) (basically a small unmanned submarine). The USV serves as gateway between the AUVs and the surface vessel, which drives the search. The USV may or may not be tethered to the Surface Vessel. The tether, if present, will provide power to the USV and will relay video and images captured by the AUVs to the vessel. Consider a search for a downed plane in the Ocean. A possible mission may consist of 10 vessels, covering say, a 10 km front. Each vessel drives 10 USVs and each USV control a network of 10 AUVs (spaced 10m one from the other). So, each vessel receives 100 videos/images from the AUVs. One can assume that the AUVs are communicating optically with the USV point to point, or through a multi-hop tree structure. The topology is determined by the Open Flow SDN controller that in this case resides on the Vessel and manages a 1km region (with 10 USVs and 100 AUVs). If water conditions and visibility are good, less than 10 AUVs may be required and the extra AUVs are stored within the USV. As water conditions worsen, the OF controller is informed by the AUV low quality signal alerts and directs the construction of a multi hop optical tree (note: the tree construction is directed via the acoustic control channel). If the water turbidity makes optical communication infeasible, communications revert to acoustics. Quality of Service and Quality of Data principles [11] can be employed to intelligently degrade from video to outline edge images [6]. Given the periodicity of the images and the multiple sources, FAMA protocols are more appropriate than S-ALOHA, so the OF Controller switches the AUVs to acoustic mode with FAMA protocols. In a tethered system, the video/image processing is performed on the vessel. All the OF commands originate from the vessel based OF controller (though load sharing with the USV may be considered). If video quality is good, the search operation can be manually guided from the vessel; specifically, by interacting with the OF Controller some AUVs can be manually directed to the Ocean floor spots of interest.

In some scenarios the entire search operation can be carried out without man in the loop (see Figure 1). In this case each USV is in charge of the AUV search patrol. Image/video processing is done on the USV. The USV hosts the OF controller proxy. The USV proxies communicate with the surface unit which hosts the main OF controller. The surface unit may be a floating energy generator based on wave motion. There is no tether, minimal information about the success of the search is propagated to the surface unit acoustically. In turn, the surface units communicate with a remote base station that supervises the entire operation. Periodically the USV surfaces to recharge. A back up USV takes its place.

A further extension to this premise is that of remote health monitoring of offshore infrastructures. For instance the AUVs can be repurposed on the fly by the OF controller to (perhaps briefly) change operational mode to that of Structural Health Monitoring, and then tasked with visual inspection of deep water assets e.g. the tethers for floating wave energy machines, underwater cables, etc.. In these scenarios the AUVs will both generate inspection data and gather and relay data from the locally deployed sensor and monitoring nodes on the installations [13].

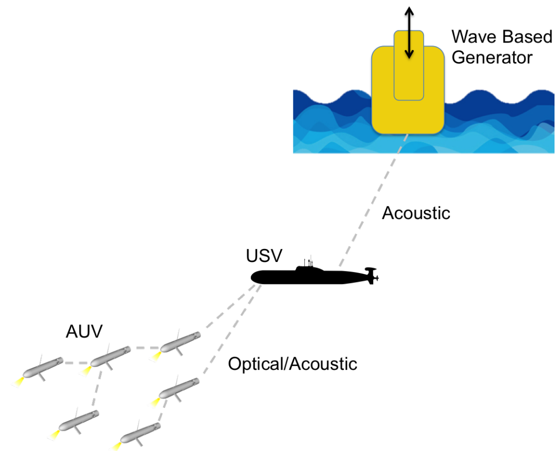

Fig. 1. Untethered, unmanned SDN architecture: the USV communicates with the wave generator acoustically and the AUVs using a combination of acoustics or optics

In order to manage the AUVs operation and purpose, the OF Controller needs to gather information from them. The location of each AUV is established by exploiting beacons from the OF Controller, pressure gauge, accelerometer, etc.. Together with relative location, the device orientation (in polar coordinates) is computed. This is necessary to align the AUV directive optical transmitter (LED cluster antennas) to form the desired topology (say, tree or star). Link capacity and water turbidity is monitored, error rates for acoustic and optical transmissions are reported, good put is recorded and remaining energy (battery power) is reported. In addition, the OF Controller commands the actuators (eg thrusters, ballast for resurfacing, etc)

In a previous study [4], we addressed another application, oil drilling pit monitoring. (see Figure 2) This is basically a surveillance operation. At the center of the system is the OF controller doubling as a data sink for the mobile AUVs that can be placed on the ocean floor, close by or in the area of operation. The static controller plays the role of the USV in the search example The controller is charged with tasks such as controlling AUV movements to arrange the network topology, disseminating routing information, receiving exploration data collected locally by the AUVs, and acting as a recharge station for the AUVs. It also acts as a data gateway to the ocean surface through various means (tethered link or other approaches).

A. Support for the OF Control Channel - JANUS

The acoustic control channel must be simple, robust, built according to well accepted standards, energy parsimonious

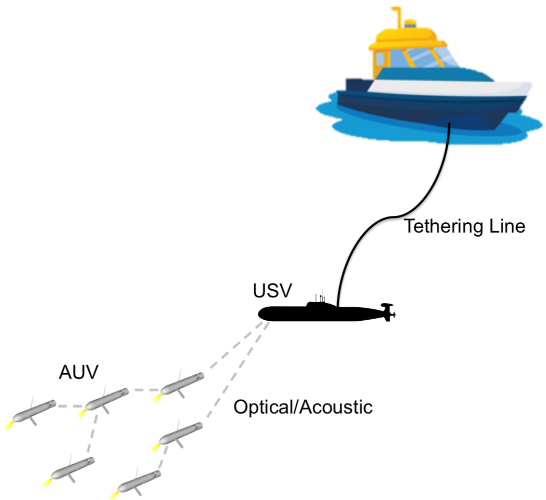

Fig. 2. Tethered SDN architecture: the USV is connected to the ship by a physical line, but directs the AUVs wirelessly using acoustics or optics

and capable of achieving communication over large distances (e.g. from surface to ocean floor). The JANUS NATO standard satisfies these requirements [12].

JANUS is an open-source robust signalling protocol for underwater communications, freely distributed under the GNU General Public License version 3 .

It has been developed at the NATO Centre for Maritime Research and Experimentation (CMRE), with the collaboration of academia, industry and government, and with the intention of creating an inter-operable communications standard. Its performance has been evaluated by many collaborating partners in waters all over the world.

JANUS has been at evaluated at centre frequencies from 900 Hz - 60 kHz, and over distances up to 28 kilometers. Packet and bit error rates have been computed as functions of the signal to the noise ratio (SNR) across time spread eriods extending from hours to months. Signal correlation times have been computed and long-term experiments by CMRE quantified robustness during variable environmental conditions.

Validation of the experimental environmental conditionals was established through a cabled network of oceanographic instrumentation which measured the ambient noise, water temperature, water velocity, internal wave and tidal information during JANUS transmission and reception for correlating message decoding performance with environmental parameters.

At the physical layer, JANUS signaling uses a coding scheme known as Frequency- Hopping (FH) Binary Frequency Shift Keying (BFSK) to transmit digital data as a sequence of short duration tones (its packet encoding process is represented in Figure 3).

FHBFSK has been selected for its known robustness in the harsh underwater acoustic propagation environment and its relative simplicity of implementation. FH-BFSK is a common phase-insensitive (incoherent) physical encoding technique, already used in commercially-produced modems, and is known to be robust across a wide variety of environmental conditions. It is also robust to packet collision, supporting a degree of

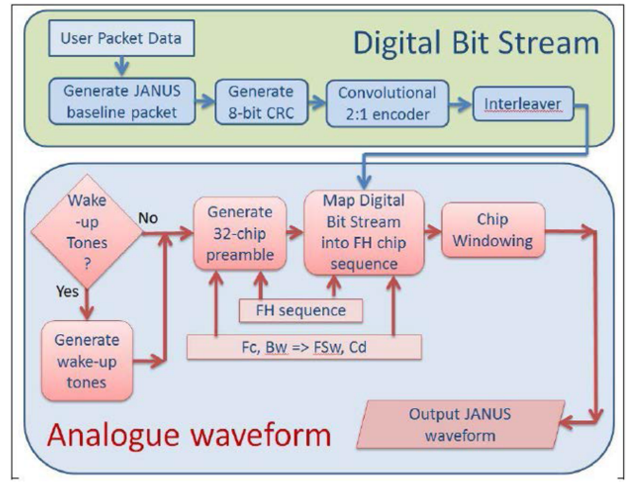

Fig. 3. Block diagram of the JANUS Baseline Packet encoding process

multiple simultaneous access that is valuable in a simple protocol with a limited medium access control complexity.

The primary advantages of using JANUS for UW acoustic OF control channel in this work are the following:

- Simplicity of design. Among the least complicated forms of acoustic communications yet devised.
- Robust to noise. This signal should be detected when the signal to noise ratio (SNR) in a given band is at better than -2 dB.
- Robust without tracking for "reasonable" amounts of relative speed (range rate).
- JANUS is a highly efficient approach to use for asynchronous, multi-access (multi-user) applications.
- Excellent for robustness in the presence of all types of interference, including intentional jamming.
- Depending on SNR, JANUS may be quite difficult for third parties to detect by conventional means; for example, by energy detectors of all forms.
- JANUS is a "constant envelope" waveform. Thus, a transmitter is not concerned with amplitude crest factors, and thus may allocate maximum power to the transmission.

B. *Support for the optical PHY*

As described earlier, the under-water SDN architecture also supports the optical physical layer in favorable conditions. Optical radios under water can transmit at data rates up to 2.28 Mbps [3], which is significantly faster than acoustic radios. Additionally, optical radios require less power and have very short propagation delay, since visible light travels at the speed of light. On the other hand, optical communications require line-of-sight between radios and are generally not omni-directional. This results in very short ranges of transmission, typically of the order of about 100 meters [5], which is comparable with the low power, short range acoustic radios. The uni-directional property of optical radios requires relative localization among radios, which is supported by UAVs. Unidirectionality makes duplex communication a possibility (ie. radios can send and receive packets at the same time). This is not possible with acoustic modems. Moreover, the

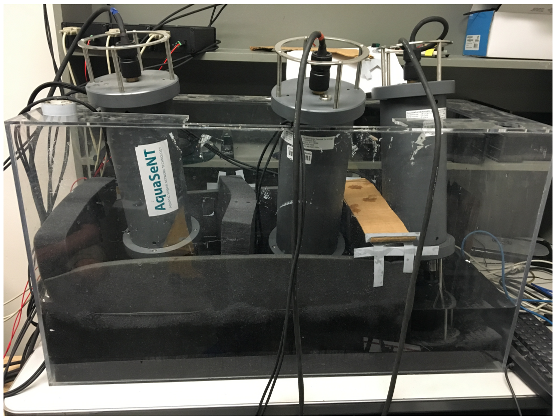

Fig. 4. Our implementation of the under-water SDN scenario in the improved WaterCom [9] testbed

directionality, though mainly seen as a disadvantage, can be valuable when covertness is a requirement, making optical radios ideal for covert military operations.

The tasks of the OF Controller in the optical PHY case are nearly identical to those in the acoustic PHY case. Here, the control plane continues to use the acoustic channel JANUS, but the data plane has now been moved to the optical radio. Due to the need for directivity in optical transmissions, the controller's knowledge about each node's location becomes even more critical. Once AUVs receive both routing information as well as network topology information, they can orientate their transmission beams toward the correct direction.

IV. Implementation

We implemented parts of the acoustic version of this system in our WaterCom [9] [10] testbed. WaterCom allows anyone to set up and execute simple experiments remotely through our server reachable via the URL <apus.cs.ucla.edu>.

There are six OFDM acoustic modems in total in our testbed. Three of these are AquaSeNT AM-OFDM-13A models whose communication range is up to 5 km, and the remainder are the lower-power educational OFDM models that can communicate up to 150m. All transducers and hydrophones are placed in the test tank as shown in Figure 4.

These six modems are connected with the WaterCom server, by which we remotely control the modems. The underwater protocol stack SeaLinx [12] is employed to provide the networking services for experiments. Different protocol modules can be loaded in the transport, network and link layers of SeaLinx to assess and evaluate their performances with different experimental configurations. For simplicity sake, in this work, the SDN controller is the server and has a wired connection to each modem, representing the devices.

V. Conclusion

In this paper we presented an underwater networking system for AUVs that uses a centralized network controller in implementing an SDN paradigm. Our design decouples the control and data planes by utilizing a dedicated control channel (JANUS) for the controller to disseminate packets to the AUVs. With this design we were able to greatly simplify the task of AUV routing, even satisfying the stringent alignment requirements that are necessitated by optical channels. Our future plans envisage inclusion of the M FAMA MAC protocol in our improved WaterCom [9] [4] underwater SDN testbed, and the deployment of our implementation in a larger body of open water so that we can create and validate realistic experimental configurations and signalling and propagation studies.

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