WaterCom

A Multilevel, Multipurpose Underwater Communications Test Platform

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ABSTRACT

Underwater Communications is very much an experimental science because of the complex medium - the water - and its unpredictable propagation properties, thus mandating experiments to validate theory. The medium is particularly challenging for the transmission of acoustic and optical signals. Thus, the true performance of a transmitter/receiver system can be evaluated only in the water. It would then appear that UW research be inevitably associated with a testbed. However, this is not always the case because UW testbeds are difficult to set up, calibrate and instrument. The purpose of the recent NSF CRI Ocean-TUNE project is precisely that of deploying inexpensive UW testbeds accessible by the Community. UCLA, as a participant in the Ocean-TUNE project, has recognized that one UW testbed cannot fit all applications and therefore has been developing WaterCom, a multilevel testing platform consisting of three testbeds - small, medium and large scale. The small testbed is deployed in a tank, with two modems; it is used for point-to-point communications at close range. It is instrumented for remote access and allows the testing of variable TX power values with different obstacles, reflected rays absorption and water purity values (for optical experiments). The medium scale testbed, deployed at the Marina del Rey UCLA boathouse, will enable remotely monitored experiments of MAC and network protocols with three nodes, one of them mobile. The large scale open water testbed is deployed in the Catalina channel. It will employ OFDM Modems as well as small submersible, mobile platforms. WaterCom will enable two types of experiments: environment measurements, like subsurface currents, presence of deposits in the water, etc, and; network protocol and application measurements in the open water. The paper describes the testbeds in detail and introduces preliminary small scale testbed measurements.

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1. INTRODUCTION

The principles, concepts and system described in this work have their genesis in the NSF CISE Collaborative Research Initiative (CI-ADDO-NEW) Ocean-TUNE[20]. The proposal envisages the "design and deployment of an open underwater testbed suite" which will "enable oceanographers to study scientific research questions, while using the testbed as a prototype for larger real-time monitoring deployments elsewhere". We start by identifying some existing platforms for the automated management and execution of scientific experiments and articulate a functional requirements set for the OceanTUNE platform. As the intent of the platform is to focus on the area of "communication and networking algorithms and protocols", a subset of recent research contributions are identified and thoroughly quantified in order to identify the systems operational modalities. Thereafter the physical properties of underwater communications technologies and devices are briefly presented as a precursor to the System Design. Three distinct deployment scenarios are introduced to underpin the job scheduler and experimental contexts, and their appropriateness is explored. Early results are presented and analysed and the paper concludes.

2. MOTIVATION

Underwater communication and networking remains an active research area for many groups. With increasing interest in exploiting marine resources comes an associated requirement for reliable communications in such environments. Many such scenarios can be satisfactorily addressed using surface radio interfaces, but others require underwater communications. The Networks Research Lab in UCLA has been active in this domain for more than a decade, with many fundamental contributions [19],[10],[17],[18]. These have been validated using the latest in modelling and simulation technologies, and more recently using an underwater acoustic modem testbed. The WaterCom system seeks to make these test facilities available to all interested researchers and parties. It will be of particular interest to those with geographic constraints (e.g. no coastline) and those for whom the cost of such a testbed would be prohibitive.

3. BACKGROUND

The Ocean-TUNE project[20] is a key enabling activity for providing remote access to in-situ, research and development, underwater communication infrastructures. This work draws on a broad cadre of existing work across a variety of domains, and integrates and extends it towards providing global community access to a unique set of scientific and experimental resources. It was clear, from the outset, that permanent deployment of offshore communications infrastructure would be prohibitively expensive, so a structured system - WaterCom - for submitting, queueing, executing, and reporting results from submitted experimental jobs was conceived. The system design supports live, staggered and future scheduled modalities, supports multiple hardware communication devices and channels, and also provisions for the integration of external simulation platforms. Upon completion a user will be able to configure an experimental set, submit it for execution, check its live execution status and emergent system messages, and download the received data and outputs. Existing experimental frameworks and job schedulers were considered in the functional design of the system.

3.1 Simulation Frameworks

Valuable input into the design process can also be garnered by exploring existing underwater simulation frameworks. There are a number of Underwater Simulation suites and frameworks that are commonly referenced in published literature. These include Qualnet[22], Sealinx[14], Desert[28], Sunset[21] and UAN[29]. The authors have worked with many of these, but recognise that different research groups have their own preferences with associated accumulated knowledge and IP. The most pertinent insight can be garnered from the EU FP7 SUNRISE project[25]. This project kicked off some time after OceanTune, and has a much more research specific remit than WaterCom. WaterCom targets all user domains from K12 upwards, and is structured to permit ready integration of other modems (acoustic and optical) by any user possessing such hardware.

The WaterCom framework provides a mechanism to integrate external simulators into an experimental configuration. The framework will call the external simulator, passing it the experimental configuration and (pointer to) the test data. Alternative remote invocation and execution modalities can be tailored to both a given simulator, a specific host platform and the requirements of a specific experimental set. In these ways we believe that the system will provide value to the Community through broader access to test fairly complex infrastructures.

3.2 Underwater Communications

The design and implementation of effective Underwater Communication Systems is challenging. Water, as a carrier medium, severely limits bandwidth, gives rise to long propagation delays (five orders of magnitude slower than radio signals), and markedly higher transmission powers (100× greater than that required for reception [30],[7]). Moreover the unreliable nature of underwater wireless channels, due to complex multipath fading, Inter-Symbol interference, surface scattering, Doppler frequency spread and suspended particulate matter (e.g. mud, organic matter, etc.), further compromises reliable data communications. The available bandwidth strongly depends on both range and frequency. Existing systems have highly variable link capacity, where the attainable range and rate product is approximately 40km-kbps. Signal propagation speed is also markedly lower than in air (1.5×10^3 m/s vs 3×10^8 m/s) - highlighting the difference in propagation delay and associated design challenges [19]. The literature also highlights the very significant transmission power requirements e.g. up to 48W for one acoustic underwater modem [7]. Moreover the loss characteristics of a transmitted electromagnetic wave are not uniform - Lucas and Yip [16] showed that the attenuation is rapid in the first ~10m of communication distance, but decays slowly thereafter, which conceivably makes communication possible up to a ~100m range [4].

3.2.1 *Acoustic*

Early underwater communications research was mostly intended for military purposes. Initial systems transmitted a few characters per minute at frequencies of ~80Hz, but exhibited long transmission range due to the low absorption of sound waves in water[24]. Teledyne Benthos have a variety of underwater acoustic modems[26] satisfying different end-use case scenarios. Data rates are typically up to 15kbps from 9 and 27kHZ using MFSK and PSK across 2-6km ranges. The AquaSent AM-OFDM-12A modems[2] are used in the WaterCom system. These have been superceded by the AM-OFDM-13A which are rated at up to 9kbps in the 21-27khZ frequency band and use OFDM. The Aquasent modems support five different transmission modes, ranging from 38bytes/block in mode 1 through to 164bytes/block in mode 4.

3.2.2 *Optical*

Optical communication systems are well established in scenarios where high throughput and security are paramount, and directional constraints are not bounding. More recently optical communication concepts and systems have been filtering down to domains where traditional wireless technologies have dominated e.g. VLC as a secure side channel in vehicular platooning, underwater optical communications systems,etc. Increasingly robust and "multi"directional optical modems are being seen in the commercial marketplace, and the military are clearly very active in this domain also.

Optical modems usually encode data by flashing LEDs or LASER and use highly sensitive detector to gather photons for decoding. Range is dependent on the brightness/intensity of the light source, detector sensitivity and water turbidity. For instance the SonarDyne BlueComm underwater modem[23] provides 20Mbps throughput at ranges up to 200m. For initial WaterCom experiments we propose a different, and more cost effective approach, combining locally constructed transmission tubes that contain underwater mirrors in the transmitter and receiver. The optical transmission hardware is kept just above the waterline - thereby avoiding waterproofing and maintenance concerns. This scenario is attractive as we can deploy modems up to 2km apart in the canal-like Ballona Creek at the UCLA boathouse[27], and simulataneously on the dock pilings at the boathouse mooring on the Marina Del Rey side. We also plan to experiment with actuated underwater mirrors to test VLC like concepts for pulsed transmissions. Figure 8 shows the creek, with the main Marina Del Rey waterway on the left in the image.

4. SYSTEM DESIGN

The WaterCom experimental framework has been designed to be cloud hosted, extensible and reliable. Experimental nodes can come online at any time, poll the cloud based job scheduler queue, locally execute their experiment set, and periodically reconnect to the cloud service to upload results and execution status information. These operational modalities support permanently connected, occasionally connected, and predominantly disconnected modalities. The actual carrier medium and protocol can range from Delay and Disruption Tolerant network techniques via satellite connections, through to wireless 5G communication links.

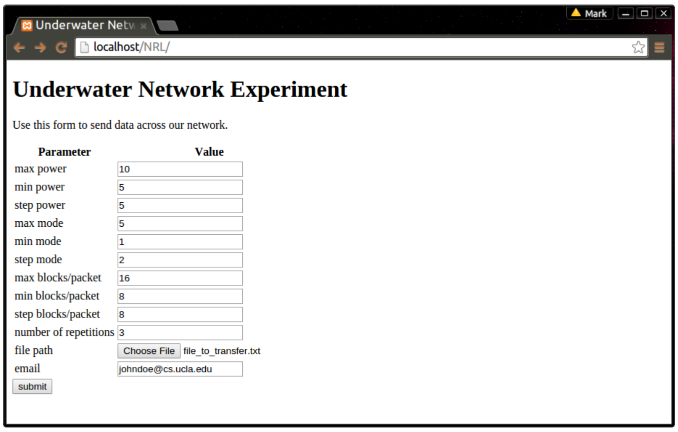

Figure 1: Submission Form

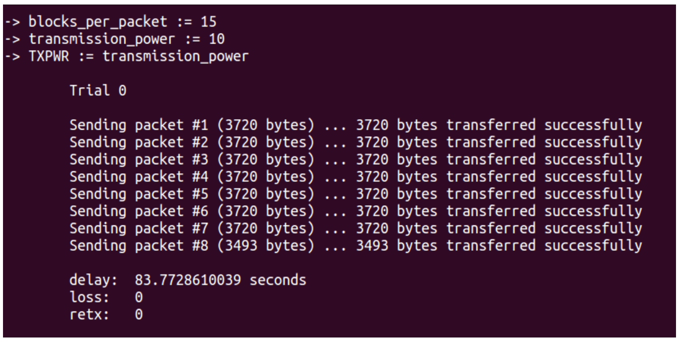

Figure 2: Summary Feedback Screen

4.1 End User Interaction

The prototype's interface is intentionally simple in order that any research or educational facility may integrate it into their activities. A skeleton submission form is shown in Figure 1, with the live experiment feedback screen shown in Figure 2. All values are sanity checked and cleaned prior to acceptance. In simplest form a user chooses acoustic, optical or both modem types. Dialogs update to present a selection of available enabled modem types in each category. Devices marked as unavailable by their operators are not presented. Selection of a specific modem type presents its parameterization interface for (initially) configuring the hardware for the experiment. In many cases the device can be subsequently reconfigured "on-the-fly" by sending the appropriate commands. Only simple experimental configurations have been implemented at this stage (point-to-point and one relay node) in keeping with the hardware available to the prototype. Having configured the hardware the user then identifies the dataset for transmission, and the number of experimental repetitions. Some sample files are selectable by simple radio-button, or a user may upload their own file(s) by selecting them. In the present system incarnation these files are commonly data files e.g. delay sensitive, Wave energy device control signalling, imaging data, etc. As the number of system nodes is expanded support for more advanced customisations, such as custom MAC or routing protocols, will be enabled. Additional information, including the users Email address, is gathered for dissemination of completed results and datasets. The experimental configuration(s) and associated dataset(s) are stored on the job scheduler for subsequent execution. A simple RSS status syndication feed will allow users to establish the status of active experiments. In principle the system can support experiments involving the streaming of data from/via a cloud provider, but remote experimental station connectivity may not facilitate this.

4.1.1 *Webserver and Job scheduler*

The webserver and job scheduler are implemented on the same system in the prototype but are designed such that they can be separately hosted on AWS or other cloud platform. Hosting on a cloud provider offers many scalability benefits, including support for on-demand instances e.g. associated with a job set, or when a Local Execution Engine comes online. The webserver receives the posted data from the experiment job submission frontend, hosts response and analysis scripts and engines, and receives the uploaded output file(s) upon completion from the Local Execution Engines. The requestor is then sent an Email link providing expiring access to the resultset. The webserver also integrates the graphing and data visualisation libraries necessary to provide a quick oversight of the data generated. Scatter and mesh plots produced by the WaterCom system in experimental runs are shown in Figures 3 and 4.

Backend logic integrated to the job scheduler performs initial submission validation, constructs job lists from the submitted entries, and prioritizes and appends job details to the appropriate scheduler queue based on input selections. The initial job scheduler implementation for WaterCom used a simple database system that was periodically polled and which leveraged the standard Unix CRON daemon to schedule execution of jobs on the test infrastructure.

4.1.2 *Local Execution Engine*

Remote, unattended deployment of modems requires that each device, or pair of devices, have an associated controller. The controller implements our Local Execution Engine. The Engine provides for in-situ control and configuration of the attached modem(s). The controller must also provide (at

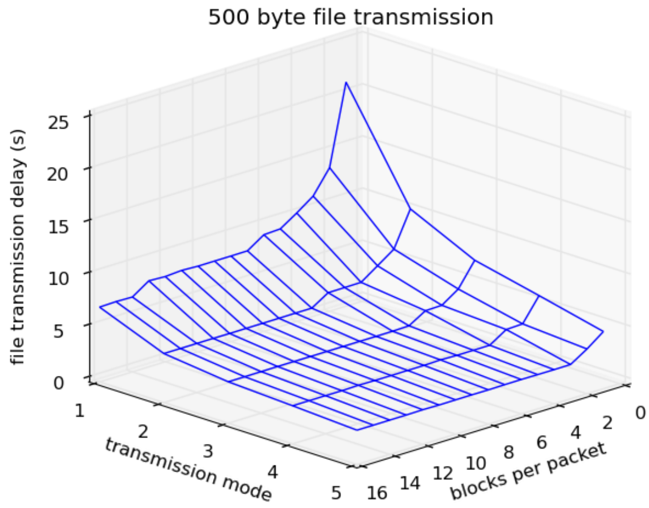

Figure 3: Presentation of results - Mesh Plot

Figure 4: Presentation of Results - Scatter Plot

least periodic) connectivity to the Internet for data exchange purposes. On initiation, and periodically, the Engine contacts and polls the AWS hosted service for waiting jobs. When the job is commenced, the Engine executes the initial modem configuration, resets the diagnostic and debug registers, and performs the transfer of the target file. On the receiving node the incoming data is streamed to a file, and modem debug and diagnostic registers are also archived. These files are uploaded to the cloud service when connectivity is next established. Provision is made for incremental status updates from transmitter, relay and receiver nodes. The initial WaterCom system implemented Local Execution Engine functionality on a single laptop connected to all devices. It is reasonable to expect Engine functionality to be deployed on a cheap, off-the-shelf embedded system platform housed in a waterproof enclosure.

4.1.3 Transmission Hardware

As noted above, the framework is structured to facilitate integration of a range of modem types - both acoustic and optical. The framework expects to connect to an API through which device specific messages are passed. For prototyping purposes three AquaSeNT AM-OFDM-12A acoustic modems were interfaced to the system. These modems use Orthogonal Frequency Division Multiplexing (OFDM) modulation and transmit in the 14-20KHz frequency range. They have a data rate of up to 9kbps and can communicate over distances of 5km and at depths up to 200m. Acoustic modems from Benthos and LinkQuest[15] have also been assessed, and their integration potential established. Provision has also been made for the integration of optical modems within WaterCom. To date there are few commodity optical modems available e.g. those by Ambalux[1] and Sonardyne[23], but they are prohibitively expensive for use in our test scenarios. In order to enable optical communication experiments within WaterCom, the NRL has conceived a low-cost experimental underwater transducer that draws on their experience with Visible Light Communication (VLC) systems. Whilst not yet fully deployed it is expected that it will enable practical, low-level underwater optical experimentation and development.

5. TEST CONFIGURATIONS

Three default test configurations are provided for in WaterCom. They differ in scale, and in the quantity and nature of the modem deployments. The relative simplicity with which experimental configurations can be generated and executed across a heterogenous set of environments is a key feature of the WaterCom system. Different experimental configurations will be active at different times, and executing jobs queued and scheduled for them. Whilst the system is technically provisioned to cope with large scale, open water experiments none are planned at present.

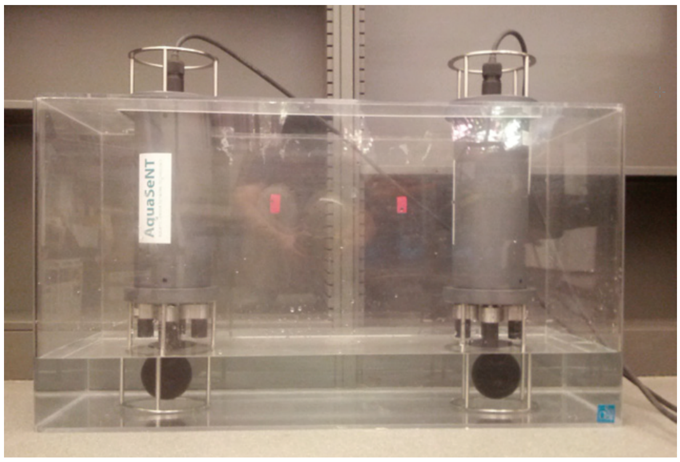

Figure 5: Test Tank [9].

5.1 Small Scale

The small scale experiments take place in a tank-like structure under laboratory conditions. The experimental tank is shown in Figure 5 and has interior dimensions 90cm × 37cm × 50cm. Two modems are used and absorbers, diffusers, and obstacles are introduced to the tank for experimental purposes. This scenario is employed to evaluate short range transmission performance in the presence of strong reflected and multipath signal effects, and water turbidity (when transmitting optically). This structure can also effectively represent transmission along a pipe or other rigid longitudinal structure. Figures 3 and 4 illustrate the experimental transmission delays measured in the small tank whilst varying the number of blocks per packet and the modem transmission mode.

5.2 Medium Scale

This experimental configuration is meant for extended deployment in a controlled marine environment. For prototyping purposes the UCLA boathouse provides a very effective host infrastructure. Modems can be attached to the dock pilings, inter-modem spacing can be easily adjusted, multi-hop experimental configurations can be arranged, and ancillary support services (power, internet connectivity) are readily available. An enclosed 2km long linear test channel is also available at the boathouse. Node mobility can be realised by transporting an active modem on a boat during experiments. An alternative is to build and customize an underwater ROV, such as in [12]. Ancillary benefits from the boathouse location include opportunities to evaluate the system for marine traffic detection and characterisation. It is further noted that many of the most common environmental challenges to underwater modems (both acoustic and optical) predominate in such an environment.

5.3 Large Scale

The WaterCom system is primarily intended for small and medium scale experimentation, but the framework can also support Large Scale offshore open water experimentation. The Ocean-TUNE project envisaged experimentation off Catalina Island in California. In such scenarios, the modem controller(s) will need to support local storage and scheduling capabilities, and to provision (at least occasionally) an online capability. Such experimental activities are of interest to wave energy companies, oil platforms, etc. in the context of optimising control and production efficiency of the infrastructure.

6. EXPERIMENTAL SCENARIOS

6.1 Experiments with Delay-aware Opportunistic Transmission Scheduling (DOTS)

DOTS is an underwater communication protocol developed by the NRL in UCLA. The ready availability of the codebase and resultsets made it a suitable choice for experimental evaluation and testing of the WaterCom system. Medium Access Control (MAC) protocols designed for terrestrial packet radio networks cannot be directly used in acoustic underwater communications because the propagation delay of acoustic signals is much greater than the packet transmission time (e.g. 0.5sec vs. 0.04sec to transmit a 256byte data packet with the data rate of 50kbps over a 750m range) - thus, carrier sensing as performed in Carrier Sense Multiple Access (CSMA) may not prevent packet collisions. However, the long propagation latency creates a unique opportunity for temporal reuse of the channel that allows for multiple concurrent packets propagating within the same contention domain. Recently a great deal of attention has been focused on exploiting temporal and/or spatial reuse of acoustic channels to improve the throughput. For instance, Slotted FAMA (S-FAMA) uses time slotting in order to lower the probability of collisions by aligning packet transmissions into slots (as in Slotted Aloha) while Propagation-delay-tolerant Collision Avoidance Protocol (PCAP) [8] allows a node to send multiple reservation requests for transmission time slots (i.e., request to transmit, RTS). In Underwater-FLASHR (UW-FLASHR) [31], time slots are divided into reservation and data transmission periods to realize efficient channel reservation and to minimize data packet losses caused by control packet exchanges. For better channel utilization, most protocols attempt to build a Time Division Multiple Access (TDMA) schedule using brute-force learning via repeated trial-and- error [31] or solving computationally hard optimal scheduling. Key insights from TDMA-based scheduling methods allow us to enhance conventional CSMA-like random channel access protocols as follows. We need to ensure that transmissions are scheduled carefully such that they do not interfere with the reception of each others' packets by their intended receivers. To satisfy this requirement, each node must evaluate the collision conditions for neighboring packet receptions prior to transmitting a packet. Recall that a collision occurs when a receiver tries to decode a packet when more than one packet arrives from different senders simultaneously [3]. The key intuition is that each node can predict whether its upcoming packet transmission will collide with another's if it has the neighboring nodes' propagation delay information and their transmission schedules. Figure 6 demonstrates the notion of temporal reuse. Node x sends a DATA packet to node z in Figure 6(a) and again at a later time another DATA packet to node y in Figure 6(b). Node z sends an acknowledgment (ACK) back to node x as node y is about to receive the transmission from node x in Figure 6(c). Finally, node y sends an ACK back to node x in Figure 6(d). This case enables the data and ACKs to be transmitted and received without any collision.

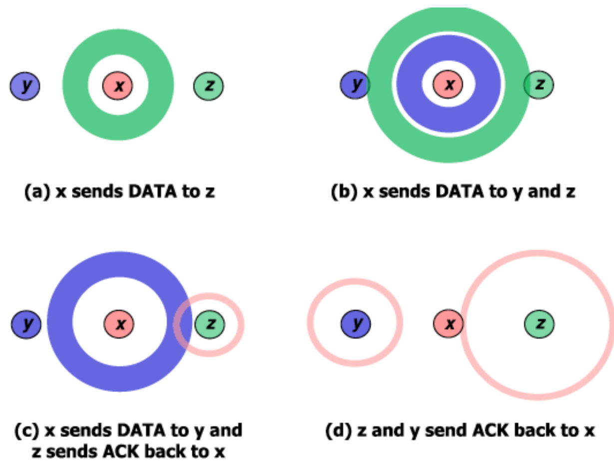

Figure 6: Temporal Reuse [19].

6.1.1 DOTS Protocol

The DOTS protocol [19] exploits long propagation delays by using passively observed one-hop neighboring nodes' transmissions to improve channel utilization. The design of DOTS is based on MACA-like random channel access with RTS/CTS. Because of this design choice, it is confronted with the problem that data transmission between two nearby nodes after RTS/CTS handshaking can collide with RTS control frames of a distant node due to relatively long propagation delays [5]. Recall that this will happen more frequently and be more expensive in underwater acoustic networks than in terrestrial radio networks due to the high latency and transmission costs. Fullmer et al.[6] identified the problem and provided the following two conditions for collision free transmission:

- RTS wait time should be greater than the maximum propagation delay - that is the propagation delay for a transmitted frame to reach its maximum transmission range.
- CTS wait time should be greater than the RTS transmission time plus twice the maximum propagation delay plus the hardware transmit-to-receive transition time.

Thus, these two conditions are the basis of DOTS protocol in order to avoid frame collisions. With the assumption of synchronization, DOTS can locally calculate the distributed transmission and reception schedules to perform concurrent transmissions when viable by promiscuously overhearing neighboring transmissions. DOTS maintains minimal internal states in a delay map database to keep track of observed neighboring transmission and reception schedules. This database is updated based on each observed frame's MAC header. In addition to standard source, destination, sequence number, frame size and Cyclic Redundancy Check (CRC) checksums in the MAC header, DOTS necessitates two additional fields in the MAC header, namely an accurate clock synchronized timestamp of when the frame was sent and an estimate of the propagation delay between the source and destination. This estimate of the propagation delay between the source and the destination of the overheard frame can be performed during the clock synchronization process by examining the time of flight information during the frame exchanges and later updated through further communications between the nodes. Moreover, the delay map database entries can expire and be removed over time with the knowledge of data size of each entry and the maximum propagation delay for each overheard frame in order to keep the number of database entries small. Whenever a node has a frame to send, it runs a transmission scheduling decision algorithm based on its delay map database to make a decision as to whether or not to begin its transmission. If no conflicts are detected, it begins its transmission; otherwise, it backs off for a random amount of time. It is important to note that unlike traditional CSMA-like protocols, DOTS allows each node to have multiple outstanding packets to receive. Since each node may miss a neighbor's RTS or CTS transmission due to channel fading in underwater, conflict detection schedules may still cause collisions. Thus, to reduce the damage and to avoid deadlock, DOTS provides for a recovery scheme [19]. Finally, since deployed nodes are moving along with the ocean current, DOTS requires a guard time to avoid invalid transmission scheduling caused by the node mobility.

6.2 The experiments

The UCLA testbeds will enable the testing of the DOTS protocol for various parameter setting. In particular, the Marina testbed with three nodes aligned will recreate the scenario depicted in Figure6. The basic set of experiments will reproduce the simulation experiments reported in [19] where throughput, delay and fairness are measured. The DOTS code will be available to remote experimenters. In addition, modified versions of the DOTS protocol and other MAC protocols that exploit temporal reuse can be tested

6.3 Representative Use Cases

The primary use cases are expected to arise from i) low-level protocol coding and validation and ii) robustness, reliability and throughput of data. Protocol validation using the prototype system leverages NRL's broad range of contributions in this field, in particular works such as M-FAMA and DOTS, where simulator validated implementations are already available for comparison. Data quality experiments can be performed using any relevant data source. Low-rate image and video transmission was successfully implemented and validated during development of the low and medium scale scenarios. Focussing on R & D uses of the WaterCom system, we were interested in the end-to-end transmission of a time-sensitive control data stream. This stream was captured from quarter-scale testing of a prototype wave-energy device. Received data quality and latency are of paramount importance as flaws in the control stream can affect production efficiency, or even result in machine damage[13].

6.4 Catalina eddies mapping using the large scale UCLA Testbed

In the Catalina eddies mapping experiment, the large scale UCLA testbed equipment will be deployed in the coastal region of the Southern California Bight, more specifically, the regions of Santa Monica Bay, San Pedro Channel, and near Catalina Island. The area is chosen due to ongoing observations of small-scale oceanographic eddies and fronts by other projects (eg SubEx by NSF CRI Co-PI B. Baschek and collaborators). The NSF CRI testbed will significantly support these experiments by providing a technology for subsurface current measurements taken simultaneously at different locations within these features. These experimental observations are currently done with sensors at different depths trailed by boats, with lack of precision. Precise measurements are essential for determining the kinetic energy, incident angle and evolution of these features that are a key element of the ocean energy budget. The proposed experiments will deliver high resolution sea surface and in situ temperature measurements that help map the eddies. Surface current measurements will be used for comparison. Aerial sea surface temperature measurements taken from the plane used in SubEx can be used to identify a suitable deployment area. UCLA's research vessels will help with the deployment, tracking, and recovery of the testbed equipment. The main motivation of these experiments is the fact that submesoscale eddies, fronts, and filaments on the scale of 10 m to 20 km represent a scientific frontier in oceanography. They are not very well sampled and have only recently been the subject of numerical modeling. These submesoscale features are intermittent in space and time and present a formidable observational challenge. In addition to their role in the energy budget of the large scale ocean circulation and their connection with local forward energy cascades, they are important for the understanding of mixing processes and the variability of the coastal ocean, also in connection with bio-

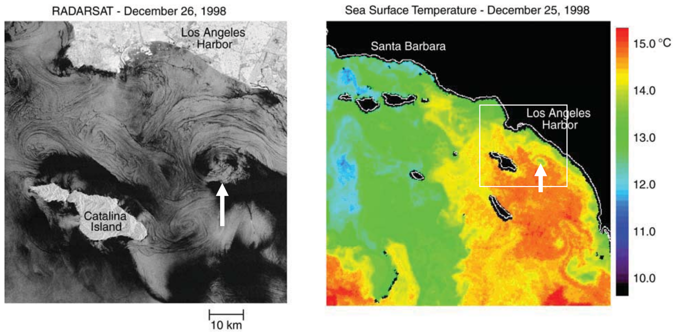

Figure 7: Small.scale eddies in Catalina Channel as seen from a) RADARSAT1 on 12/26/1998, and b) associated sea surface temperature image from AVHRR from 12/25/1998. In the SAR image, eddies are largely detectable by a series of dark spirals associated with the convergence of surfactants tracing the eddy circulation fields. Only the eddy marked by the arrows has a clear (cold) temperature signature. We speculate that the SST expressions of the eddies, or lack thereof, may be related to the eddies' scale, period of life.cycle, generation mechanism, or some combination of these [11].

geochemical processes. The proposed study will improve the understanding of the physical properties and generation mechanisms of submesoscale eddies, fronts, and filaments and their role in the coastal circulation through a multifaceted study that combines coincident satellite and in situ testbed within the coastal region of the Southern California Bight.

We recall that the UCLA large scale testbed will consist of surface nodes either placed on buoys or carried by boats, bottom nodes anchored to the sea floor and drifters or ROVs (a few inexpensive versions are now coming to market or can be constructed). All nodes (including buoys, bottom nodes, and drifters) are equipped with acoustic modems (some carry high-speed OFDM acoustic modems). Some nodes will be also equipped with optical LED transceivers. In this experiment, the drifters will play a key role. They will be used to conduct measurements of eddies and fronts, where an accurate flow-tomography of underwater currents and eddies obtained from drifters will complement the data collected from the bottom nodes. The drifters are depth controlled by an air pocket. Their acoustic modems are much simpler than those of static nodes as, in most experiments, they are simply used for positioning. The sensors drift in their experimental location, under observation, at a preprogrammed depth. They compute and record their position every few seconds based on the acoustic beacons generated by a combination of surface buoys, anchored nodes and boats that move with the drifters. At the end of the drift experiment, upon recovery from water, the drifters provide an accurate flow-tomography of underwater currents and eddies complementing the data from the anchored nodes. Optionally, the drifters can transmit on periodic intervals their intermediate results to the surface nodes, allowing for real time distance monitoring of the experiment. This real time, remote monitoring will allow researchers (in situ or remote) to request real time modifications to an experiment in progress, for example launch more drifters, or alter the drifters' depth.

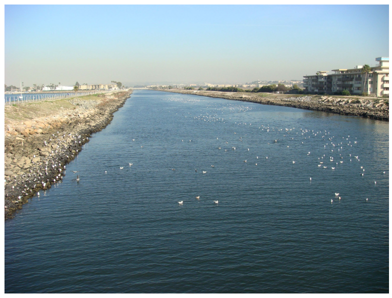

Figure 8: Ballona Creek

7. CONCLUSIONS

This paper describes the WaterCom system. WaterCom is a multilevel, multipurpose underwater experimental platform, inspired by the successful NSF CRI Ocean-TUNE project. WaterCom opens up underwater communications resources to the Community at large. The system is designed to be straightforward to use - and can hide the complexity of underwater modems from end users. The system design of the working prototype is elaborated in full, and many pending enhancements are discussed. The system leverages protocols developed in UCLA as test and validation cases for the Network Protocol capabilities of the system, and some preliminary results from the small scale experiments are presented.

8. ACKNOWLEDGEMENTS

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