S&T organization

CMRE

Book of Abstracts of the

Third Underwater Communications and Networking Conference - UComms'16

Aug.30 - Sep.1 2016, Lerici, Italy

UComms

IEEE

OES IEEE Oceanic Engineering Society

Office of Naval Research USN ONR Science & Technology

Allied Command Transformation

Office of Naval Research USN Global Science & Technology

KONGSBERG

ATLAS ELEKTRONIK
A joint company of ThyssenKrupp and Airbus DS

1929 S

FONDAZIONE CASSA DI RISPARMIO DELLA SPEZIA

CARISPEZIA CRÉDIT AGRICOLE

Keynote speech

Underwater Communications: ieri, oggi e domani

Milica Stojanovic, Northeastern University, MA, USA

In this presentation, we take a tour of underwater communications, scrolling thorough the past, present and future of key technologies, signal processing and networks. We begin by briefly summarizing "the achievements of yesterday"—those that have resulted in mature technology that is now routinely deployed in various scientific and commercial systems. We follow with observations on today's research efforts, touching upon the issues of channel estimation and equalization for single- and multi-carrier communication systems, acoustics and optics, system integration and networking. At present, there is no dominant application (market) that drives technology development, and the challenge to the scientific community is to continue to provide fundamental building blocks that will push the application limits. The underlying issues are closely intertwined with our major question: What is the future of underwater communications? Or, if you prefer, what are the underwater communications of the future? We invite the audience to participate in answering this question, so if you are reading these lines, think about an item or two that you would put on the "tomorrow" list.

Applications and Requirements

(Chairs: Roald Otnes and Vladimir Djapic)

Acoustic Communication and Navigation in the New Arctic - A Model Case for Environmental Adaptation

Henrik Schmidt (Massachusetts Institute of Technology)
Toby Schneider (GobySoft, LLC)

The particular sensitivity of the Arctic to climate change is well established, and the significance to undersea operations can be dramatic. As part of the recent ICEX16 US Navy Exercise in the Beaufort Sea, MIT deployed an autonomous underwater vehicle with a towed hydrophone array below the ice cover for assessing the climate-induced changes to the undersea ambient noise environment. The safe underwater operation depended on navigation updates from the submarine tracking range being communicated to the vehicle for fusion with the onboard inertial navigation.

However, the changes in the environment severely deteriorated the tracking performance compared to previous deployments. The reason was clearly associated with a previously observed neutrally buoyant layer of warm Pacific water persistently spreading throughout the Beaufort Sea, which severely alters the acoustic environment with dramatic effects for both long and short range acoustic sensing, communication and navigation. This paper describes the effects observed and discusses how robust acoustic connectivity in this environment makes it paramount that the manned or unmanned undersea platforms are capable of adapting to the environment for sensing, communication and navigation.

The SWIGacoustic Standard

Andy Smerdon (Aquatec Group Ltd)
Francisco Bustamante (Evologics GmbH)
Mike Baker (OTM Consulting)

This paper describes industry efforts to develop an underwater acoustic communications standard for the offshore energy community. The Subsea Wireless Group (SWiG), an international oil and gas industry network comprising operators, installers, and technology companies, assessed a variety of potential use cases and possible routes to develop a common standard, culminating in the selection of the JANUS standard as a template. The paper explores typical use cases, the benefits of

standardisation for technology developers and users, identification of gaps in the JANUS standard, and current progress in developing the standard.

Human-Robot Interaction Underwater: Communication and Safety Requirements

Nikola Miskovic (University of Zagreb Faculty of Electrical Engineering and Computing)
Murat Egi (DAN Europe)
Đula Nađ (University of Zagreb Faculty of Electrical Engineering and Computing)
António Pascoal (ISR - Instituto Superior Tecnico, Universidade de Lisboa)
Luis Sebastiao (ISR - Instituto Superior Tecnico, Universidade de Lisboa)
Marco Bibuli (CNR-ISSIA)

Safety is of particular interest when performing research related to human--robot interaction in unpredictable and hazardous underwater environment. Special attention is devoted to safety requirements within FP7 project "CADDY - Cognitive Autonomous Diving Buddy" in order to reduce hazards during experiments, since divers relying on technology for life support are exposed to additional risk of trauma as a consequence of impact with a marine vehicle.
This paper focuses on the risk assessment of human--robot interaction in the underwater environment within the scope of CADDY project. Each vehicle comprising the CADDY fleet is analyzed for a number of risks, and an overall assessment is provided showing the appropriateness of selected vehicles for the application. Also, the acoustic communication scheme used in the project is described, as a means of efficient and robust navigation data exchange for the purpose of minimizing the risk of trauma due to unwanted contact between the vehicles and the diver.

Underwater Communication Requirements in Coordinated Autonomous Manipulation: the MARIS Project

Davide Fenucci (Department of Information Engineering, University of Pisa)
Andrea Caiti (Department of Information Engineering, University of Pisa)
Enrico Simetti (DIBRIS, University of Genova)
Giuseppe Casalino (DIBRIS, University of Genova)

This paper addresses the communication requirements needed within the MARIS project, which involves several Italian institutions. The goal of the MARIS project is to develop technologies for autonomous underwater interventions, in particular to enable two floating manipulators in executing joint grasp- ing and transportation activities. In this context, communication issues are mainly related to the information exchange needed by the cooperation algorithms during all the phases of the mission, in particular

in the coordinated transportation. Simulation results show the expected performances of the cooperative algorithm as the communication rate changes. Based on these results, a strategy to meet the requirements imposed by the cooperation and to achieve the mission objective with the available devices is presented.

Effects of Metal Structures on Magneto-Inductive Coupled Coils

Niaz Ahmed (Missouri University of Science and Technology)
Yahong Zheng (Missouri University of Science and Technology)
David Pommerenke (Missouri University of Science and Technology)

This paper analysizes the effects of metal structures in near-field Magneto-Inductive (MI) communication systems, where the transmitter and/or receiver coils may be close to large metal structures that has high magnetic permeability and conductivity. EMCoStudio simulations show that the presence of metal structure help to increase the coupling magnitude if placed nearby the transmit and receive coils, but reduces significant if placed between the transmit and receive coils.

Sub-Ice Glider Navigation & Communication
("Off-the-record" paper)

Andrey Morozov (Teledyne Marine)
Dale Green (Teledyne Marine)
Clayton Jones (Teledyne Marine)

Navigation and telemetry for AUVs operating in the Arctic currently rely on GPS and satellite communications that are poorly suited for polar areas covered by ice restricting access to the sea surface. Although the data rate of long range acoustic communications is much less than satellite communications, and the precision of acoustical navigation is less than GPS, underwater acoustic systems are the only way to provide geo-location and telemetry in ice-covered regions. The Teledyne broadband sound sources with precision clocks can provide underwater navigation in the Arctic, with frequency and signals selected for the ranges of interest, which span tens to thousands of kilometers. Approaches considered here for low-frequency sources include broadband and tunable resonant transducers in a frequency range 5-1000 Hz: dual-resonant sources; tunable organ pipes and gas-filled seismic sources. While light and small dual-resonant composite pipe sound sources in a frequency range 500-1000 Hz can provide low-data rate communications with gliders at the distance 100-300 km, swept frequency sound sources in 150-500 Hz range can provide navigation signals for thousand kilometers;

gas filled seismic sources in frequency range 5-150 Hz are useful for a global ocean navigation to cover tens thousands of kilometers.

Physical Layer In Acoustic Communications

(Chairs: James Preisig, Grant Deane and Costas Pelekanakis)

Decision Tree-Based Adaptive Modulation for Underwater Acoustic Communications

Costas Pelekanakis (CMRE)
Luca Cazzanti (CMRE)
Giovanni Zappa (CMRE)
João Alves (CMRE)

Underwater acoustic channels are characterised by non-stationary fading statistics and consequently, a modulation scheme optimally designed for a specific fading model will underperform when the channel statistics change. This issue can be alleviated by using adaptive modulation, i.e., the matching of the modulation scheme to the conditions of the acoustic link. However, selecting signals from a broad range of bit rates is tedious because one needs to know the relationship between the bit error rate (BER) and all relevant channel characteristics (e.g., multipath spread, Doppler spread and signal-to-noise ratio). In this work, this relationship is extracted from large amounts of transmissions of a phase-shift keying (PSK) single-carrier modem. In particular, a decision tree is trained to associate channels with modulation schemes under a target BER. The effectiveness of the proposed tree method is demonstrated by post-processing data from two experimental links off the coast of Faial Island, Azores, Portugal.

Energy-efficient OFDM Bandwidth Selection for Underwater Acoustic Carrier Aggregation Systems

Xueyuan Zhao (Rutgers University)
Dario Pompili (Rutgers University)
João Alves (CMRE)

The energy efficiency of underwater acoustic carrier aggregation in Orthogonal Frequency Division Multiplexing (OFDM) systems is studied and an energy efficient aggregation bandwidth selection method is proposed. Via simulations it is found that (i) the aggregation bandwidth has an optimal value maximizing the energy efficiency, (ii) this optimal aggregation bandwidth decreases with increasing distance, and (iii) the energy efficiency at this optimal bandwidth drops significantly for distances above 5 km. Based on these results, an energy-efficient aggregation bandwidth selection method is proposed for an underwater system composed of a surface buoy and Autonomous Underwater Vehicles (AUVs). The proposed method is expected to optimize the

transmission energy utilization by feeding back the optimal bandwidth value from the receiver to the transmitter for different distance settings. To validate the results under varying acoustic channel conditions, field experiments on the LOON testbed hosted at the NATO STO Centre for Maritime Research and Experimentation (CMRE) are currently ongoing.

Iterative Sparse Channel Estimation for Acoustic OFDM Systems

Sayedamirhossein Tadayon (Northeastern University)
Milica Stojanovic (Northeastern University)

We propose a method for channel estimation in orthogonal frequency division multiplexing (OFDM) systems with an array of receiving elements. In contrast to traditional methods, which target the equivalent sample-spaced channel taps, this method targets the physical propagation paths whose delays are not restricted to the sample-spaced grid. The path delays are estimated jointly with the path gains and the angles of arrival, exploiting coherence between the array elements. Numerical results illustrate superior performance as compared to tap-based channel estimation, as well as additional gain available from spatial correlation across the array elements.

Uncoded Acoustic Communication in Shallow Waters with Bursty Impulsive Noise

Ahmed Mahmood (National University of Singapore)
Mandar Chitre (National University of Singapore)

The shallow underwater acoustic channel offers a challenging environment. Besides long delay spreads caused by multiple surface-bottom reflections, the channel is time variant as well. In tropical waters, the problem is compounded further by impulsive noise created by snapping shrimp. Conventionally, the noise process is modeled by white impulsive noise. However, in reality, snapping shrimp noise depicts memory and is thus bursty as well. We investigate the performance of a high-rate uncoded acoustic communication system operating in tropical shallow waters. The stationary α-sub-Gaussian noise with memory order m (αSGN(m)) model is employed as it characterizes both the temporal and amplitude statistics of snapping shrimp noise. We show that there is a stark deviation from the expected performance of the white maximum-likelihood (ML) detector when the ambient noise is αSGN(m) (m > 0). Moreover, we derive the ML detector for the shallow water acoustic channel with additive αSGN(m) and compare its performance to that of its white counterpart.

Blind Equalization of Underwater Acoustic Channels using Implicit Higher-Order Statistics

Koen Blom (TNO)
Henry Dol (TNO)
André Kokkeler (University of Twente)
Gerard Smit (University of Twente)

In order to reduce the length of transmission time slots and energy consumption of underwater modems, this work focuses on equalization without the need for training sequences. This type of equalization is known as blind equalization. A blind equalizer cascade based on higher-order statistics is presented and evaluated using sea-trial replay data. The subcomponents of the cascade use increasingly stringent nonlinear cost criteria rooted in the constant modulus algorithm. Initial results reveal that the cascade can cope with the time variance of a realistic channel and largely mitigates its convolutional error.

Model-Based Signal Detection in Snapping Shrimp Noise

Ahmed Mahmood (National University of Singapore)
Hari Vishnu (National University of Singapore)
Mandar Chitre (National University of Singapore)

In a number of scenarios, detecting the presence or absence of a known signal may be of practical interest. One such example lies in a communication setting, where packet detection is a vital first step to decode transmitted data. The detection problem can be formulated as a binary hypothesis test within the Neyman-Pearson (NP) framework. Our scenario of interest is warm shallow waters, where the sea floor is inhabited by colonies of snapping shrimp. The ambient noise in such a case is impulsive and exhibits memory. We investigate the performance of optimal detectors corresponding to four additive noise models in snapping shrimp noise. In the literature, proposed detectors typically take only the amplitude statistics of the noise process into account. By also considering the memory, we show that there is substantial improvement in detection performance. The detector in the latter case is based on the recently introduced stationary α-sub-Gaussian noise with memory order m (αSGN(m)) model, which effectively characterizes the temporal amplitude statistics of the snapping shrimp noise process.

Adaptive Power Allocation for Noncooperative OFDM Systems in UWA Interference Channels

Antony Pottier (Telecom Bretagne)

Francois-Xavier Socheleau (Telecom Bretagne)
Christophe Laot (Telecom Bretagne)

Noncooperative underwater acoustic (UWA) communication systems are prone to interfere with each other since the limited resource offered by the channel is not regulated by any standard. Mutual inteferences can significantly degrade the performances of such systems and it is necessary to find policies allowing UWA devices to access the same physical resource. In this paper, we consider noncooperative UWA OFDM systems competing to access the same portion of the spectrum. We show that an efficient decentralized power allocation strategy can be achieved when all the communication links apply a waterfilling policy only based on little knowledge about their environment. Numerical simulations performed with real UWA channels sounded at-sea demonstrate the relevance of our approach.

Autonomous Power Control For Acoustic Modems
("Off-the-record" paper)

Dale Green (Teledyne Benthos)

Adaptive Power Control is a capability in which the acoustic modems make autonomous decisions to adjust their transmit power levels to provide reliable acoustic communications and ranging measurements at the lowest possible signal to noise ratio (SNR). The algorithm uses a single handshake to establish the minimum transmit power level for communications between two modems, then monitors background noise to enable future communications without the need for further handshaking.
The Adaptive Power Control algorithm requires the modem to both characterize the background noise and to accurately measure SNR. An algorithm to measure and report background noise was validated and added to the modem. The Teledyne Benthos (TB) modem already had an ability to measure SNR, but this limited version was only valid for very modest multipath conditions. We developed an extension to the existing algorithm which properly incorporates the energy contained in all significant paths. We also developed a separate algorithm appropriate for other signalling schemes with a different acquisition structure, and demonstrated the close performance between the two methods. Several at-sea experiments were conducted, with extensive data collected to support the validation of our algorithms. We conducted an extensive evaluation of the SNR requirements for good receiver performance using simulation in additive white Gaussian noise (AWGN). The evaluation was made for all data rates available using our standard multi-channel M-ary frequency shift keyed (MFSK) signalling and for frequency hopping (FH), and other methods as well. The analysis used a completely known signal (equivalent to a single direct-path environment), so effects such as range rate and time-varying channels were not included. However, all of these methods use

non-coherent demodulation which tends to add the energy in all multipaths, so our new SNR-measurement algorithms, which inform the modem of the total available energy, are appropriate. Until at0sea experience suggests otherwise, we add 2 dB to the required (AWGN) SNR to account for real-world, at-sea conditions.

We have developed the following:

1. The ability to measure background noise power in an appropriate way
2. The ability to measure SNR in a way that incorporates all significant (multipath) energy
3. Tabulated the required SNR for all available modulations schemes.

Our present efforts identified the need to incorporate range as a metric for power control. We believe this is an important area for future study, because it is application and scenario dependent. However, it is not addressed here. Aside from range implications, we have identified, developed, and implemented in the modem, a complete adaptive power control system appropriate for static geometries.

Networking, Localisation and Scheduling

(Chairs: Lee Freitag, Chiara Petrioli and Andrea Munafò)

Collaborative Localization of Vehicle Formations Based on Ranges and Bearings

Beatriz Ferreira (ISR - Instituto Superior Técnico, Universidade de Lisboa)
João Gomes (ISR - Instituto Superior Técnico, Universidade de Lisboa)
Cláudia Soares (ISR - Instituto Superior Técnico, Universidade de Lisboa)
João Costeira (ISR - Instituto Superior Técnico, Universidade de Lisboa)

We examine the problem of jointly determining the positions of multiple underwater vehicles based on a set of pairwise range and bearing measurements taken over time. This extends prior work on the so-called (static) collaborative localization paradigm where a hybrid approach was proposed for seamless instantaneous fusion (i.e., no time dependence) of range and bearing measurements. To incorporate time we add to the original convexified least-squares cost function a regularizing term that penalizes deviations between predicted and computed vehicle positions at a given instant. The method operates progressively over time, with past estimates used for prediction at the current instant assuming a very simple quasi-linear motion model. The method is amenable to parallelization, with simple gradient-like updates. Numerical results demonstrate promising accuracy gains (reduction on the order of 10% in terms of root-mean-square positioning error) in simulations inspired by an underwater geoacoustic surveying application.

On the Accuracy of Passive Multipath-Aided Underwater Range Estimation

Elizaveta Dubrovinskaya (IMDEA Networks Institute, Madrid; Universidad Carlos III, Madrid)
Ivor Nissen (Research Department for Underwater Acoustics and Marine Geophysics (FWG), WTD71 Kiel)
Paolo Casari (IMDEA Networks Institute, Madrid)

We consider range estimation algorithm based on the time differences between different arrivals of the signal transmitted by an anchor node of known location. We assume that only the anchor node can transmit information. We consider the geometry of the problem in the simplified case of a constant sound speed profile (SSP), and argue that the more realistic case of a non-constant SSP can be still tackled as if the SSP were constant, provided that an effective sound speed value is computed based on the geometry of the signal propagation.
We then evaluate the accuracy of the latter approach in the presence of errors affecting

different quantities required for the range estimation process, including the TDoA values, the bottom depth, and the depth of the node to which the range is computed. Our results show that our approach offers improved accuracy with respect to a baseline LSE estimator.

A Distributed ID Assignment and Topology Discovery Protocol for Underwater Acoustic Networks

Roberto Petroccia (CMRE)

This paper presents a new protocol to self assign node IDs in an Underwater Acoustic Network (UAN). The proposed solution, termed DIVE for Distributed Id assignment and topology discoVEry, is fully distributed and self-adaptive. While assigning the node IDs, additional information is shared to discover the other nodes in the network, the type of these nodes (static or mobile), and the number of hops to reach them. The DIVE protocol exploits link quality information to increase its reliability and robustness against message losses. The protocol performance has been evaluated under a variety of networking scenarios including node mobility, and node addition and removal.The results show that DIVE is an efficient and reliable solution for node ID assignment and network discovery, which scales with the network size in the presence of a unreliable channel.

Unslotted Transmission Schedules for Practical Underwater Acoustic Multihop Grid Networks with Large Propagation Delays

Prasad Anjangi (National University of Singapore)
Mandar Chitre (National University of Singapore)

In a recent work, a regular grid-based network topology with multihop relaying was investigated. A transmission strategy which maximizes the throughput while exploiting the large propagation delay was presented, and the upper bound on throughput established. However, deployments of communication nodes in the ocean inevitably result in slight positional deviations from the expected locations of the nodes, a departure from the perfectly aligned regular grid networks assumed. The irregularity in the grid network due to deployment errors degrades the network throughput significantly. We consider this practical problem and propose an algorithm to compute unslotted transmission schedules. We formulate the scheduling problem as a Mixed-Integer Linear Problem (MILP) and compute throughput-maximizing schedules. We demonstrate the throughput gain compared to the existing state of the art techniques

and verify the solution in the simulator for various random instances of the grid network deployment.

Experimental Demonstration of Super-TDMA: A MAC Protocol Exploiting Large Propagation Delays in Underwater Acoustic Networks

Prasad Anjangi (National University of Singapore)
Mandar Chitre (National University of Singapore)

The potential of exploiting large propagation delays in underwater acoustic (UWA) networks to maximize the network throughput is established in the recent past. Transmission scheduling strategies have been proposed to take advantage of large propagation delay. Super-TDMA is one among such Medium Access Control (MAC) strategies proposed. It is a form of Time Division Multiple Access (TDMA) protocol in which multiple transmissions are allowed in the same time slot and hence concurrently propagate in the medium. We present the implementation challenges of Super-TDMA on underwater acoustic modems and the experimental results demonstrating interference alignment, the crossing of simultaneously transmitted packets in water, and the time synchronization among the deployed nodes in the network.

Efficient Link Discovery for Underwater Networks

Roee Diamant (University of Haifa)
Roberto Francescon (University of Padova)
Michele Zorzi (University of Padova)

We describe an efficient method to discover the topology of underwater acoustic networks (UWANs). By knowing the network topology, nodes can determine destinations and routing possibilities for their packets, and schedule transmissions accordingly. To detect the network topology, an initial phase is employed. Our algorithm aims to reduce the time overhead of this initial phase while accurately discovering acoustic links. To that end, our algorithm allows simultaneous transmissions from different nodes while controlling the number of possible collisions in an optimized fashion. Experimental results from the 14~days ALOMEx'15 sea expedition show that our algorithm is able to accurately detect the network topology in a much shorter time compared to benchmark methods.

Near real-time improved UUV positioning through channel estimation

Renato Vio (Naval Postgraduate School)
Roberto Cristi (Naval Postgraduate School)
Kevin Smith (Naval Postgraduate School)

Underwater navigation systems are susceptible to a wide variety of errors. A technique to accurately update the position of an autonomous system, while underwater, is extremely desirable. The primary objective of this work is to enhance the navigational and positioning accuracy of Unmanned Underwater Vehicles (UUVs) by networking a number of Unmanned Surface Vehicles (USVs) utilizing underwater acoustic modems and acoustic travel time calculations. The development of a tracking algorithm based on the Extended Kalman Filter (EKF) and the use of underwater acoustic ray tracing algorithms to estimate accurate ranges between USVs and UUVs are demonstrated. A combination of the EKF with a Smoothing Algorithm was developed and extensively tested with synthetic data. To validate the concepts, the tracking algorithm was applied to data collected during sea tests that took place in Monterey Bay in August, 2015.

Simulation, Models and Test Beds

(Chairs: Sérgio Jesus and Paul vanWalree)

An analysis of 1 and 2-D arrays for adaptive multichannel equalizers in underwater acoustic communications
("Off-the-record" paper)

James Preisig (JPAnalytics, LLC)
Grant Deane (Scripps Institution of Oceanography,UCSD)

Hydrophone arrays for multichannel equalizers are used to spatially filter the received signal and mitigate the negative impact of multipath-induced Intersymbol Interference (ISI) and ambient noise. While the multipath structure in the ocean is primarily vertical, the ambient noise structure is both horizontal and vertical. Thus, as SNR is decreased the optimal configuration of a hydrohone array is expected to transition from that of a vertical line array to a 2-D geometry with both horizontal and vertical aperture. This paper presents an analysis of the impact of the spatial structure of the acoustic multipath and ambient noise on equalizer performance and a methodology for quantifying the impact to be used in optimizing receiver array geometry. The accompanying talk will present the results of the trade-study of array geometry as a function of SNR based upon the methodology developed here.

Very High Frequency Noise Sources in the Littoral Zone

Grant Deane (Scripps Institution of Oceanography,UCSD)
James Preisig (Woods Hole Oceanographic Institution)

Recent interest in very high frequency (VHF, here defined as > 300kHz) underwater acoustic communications has motived a study of VHF noise sources in the littoral zone. The Littoral is a special environment for underwater ambient noise. Near shore bathymetry induces wave breaking and wave-sediment interactions, both of which generate underwater noise, and a variety of marine organisms can radiate noise across a broad acoustic spectrum. Two potential VHF noise sources, breaking waves and snapping shrimp, are considered here. Measurements of the noise radiated by breaking laboratory waves are presented, which show that wave noise can extend to at least 400 kHz. Model calculations of the pulse of sound radiated by a collapsing cavitation bubble generated by a snapping shrimp jet show the potential for significant spectral components up to 1 MHz. The implications for these noise sources on the temporal and spatial distribution of the VHF noise field are discussed.

Tethered Balloons and TV White Spaces: A Solution for Real-time Marine Data Transfer at Remote Ocean Areas

Filipe Teixeira (INESC TEC)
Tiago Oliveira (INESC TEC)
Mário Lopes (INESC TEC)
José Ruela (INESC TEC)
Rui Campos (INESC TEC)
Manuel Ricardo (INESC TEC)

Autonomous Underwater Vehicles and Remotely Operated Vehicles are useful in industries such as offshore Oil and Gas, deep sea mining, and aquaculture, where inspection missions are frequent. While underwater communications are mainly done using acoustic links, retrieving data from these devices to shore is still an open issue, especially when we consider the high cost of satellite communications. In this paper, using ns-3 simulations, we evaluate the ability of the communications solution being developed in the BLUECOM+ project to enable real-time marine data transfer at remote ocean areas. Through the usage of tethered balloons, TV white spaces frequencies, and multi-hop communications, the BLUECOM+ solution enables cost-effective, broadband connectivity to the Internet at remote ocean areas, using standard access technologies such as GPRS/UMTS/LTE and Wi-Fi. Simulation results show an expected range exceeding 100 km from shore using only two nodes at sea, with bitrates over 1 Mbit/s.

Wide-band shallow acoustic channel simulation with realistic Doppler and delay spreading for 3D evolving rough surfaces

Michael Caley (Curtin University of Technology)
Alec Duncan (Curtin University of Technology)

A phase-coherent shallow underwater multipath channel simulation is described that combines the eigenpath amplitude/delay responses from a ray-tracing model for the flat-surface channel geometry, with the time-varying micro-path responses derived from signal interactions with successive 3D realisations of the rough surface. The time-varying rough surface response is calculated from a discrete series of time-circular 3D rough surface realisations, allowing the resulting time-circular channel impulse response to be used with test signals of arbitrary length. The simulated channel is synthetically probed to present comparisons of Doppler and delay spreading characteristics of measured and simulated replica channels.

Interoperability and Standards

(Chairs: Dale Green and João Alves)

Analysis of JANUS and underwater telephone capabilities and co-existence

João Alves (CMRE)
Justus Ch. Fricke (Bundeswehr Technical Centre for Ships and Naval Weapons, Naval Technology and Research (WTD 71))

This document aims at offering a concise look into the co-existence of Underwater Telephone and JANUS digital communication methods. This topic is of particular interest as both methods (one a well-established STANAG and the latter in the process to become a STANAG) have partially overlapping frequency bands. The two techniques are briefly described and the specific interference mitigation strategies built-in in JANUS are presented. The document then focuses on a series of experiments conducted during the REP14-Atlantic sea trials. These experiments had two main objectives: 1) Measuring the impact of an interfering JANUS signal on the intelligibility of voice messages and 2) assessing the capabilities of both techniques under similar conditions and validation of the JANUS Medium Access Control scheme. Experimental setup, analysis and results are presented for the different activities.

Experiences with JANUS and efforts towards a common heavy-duty underwater communication stack

Henry Dol (TNO)
Koen Blom (TNO)
Ernest Van Der Spek (DMO)

A new European Defence Agency (EDA) project is currently being set up, called SALSA, in which five European nations are working towards a common underwater communication stack for heavy-duty purposes, i.e., a rugged protocol stack that can serve as the future communication backbone for naval operations involving autonomous underwater vehicles (AUV) and bottom nodes. The emerging NATO standard JANUS is envisioned as first-contact protocol in the SALSA stack, enabling ad-hoc extensions of the underwater network such as in-mission upscaling of the number of AUVs in joint operations. In this context, the JANUS modulation has been tested at sea for several communication ranges and Doppler shifts, comparing its performance with the candidate physical-layer protocol of the SALSA stack.

Fostering the Use of JANUS in Operationally-Relevant Underwater Applications

Roberto Petroccia (CMRE)
João Alves (CMRE)
Giovanni Zappa (CMRE)

This paper presents the use of JANUS in operationally-relevant underwater applications. JANUS is an open, simple and robust digital coding technology currently in process to become a NATO standard. Two underwater scenarios have been considered: 1) Broadcast of underwater AIS and situational awareness messages; 2) First contact and language switching.
The JANUS physical coding scheme has been used by the underwater nodes as the common "language" to share data and to negotiate the switching into a different language, if needed. Field experiments have been conducted to test and validate the proposed approach. Different and heterogeneous configurations have been considered. In this paper we present the collected results and lessons learnt which are a promising starting point for fostering the research in this area.

Watermark: A realistic benchmark for underwater acoustic modems

Paul vanWalree (Norwegian Defence Research Establishment (FFI))
Roald Otnes (Norwegian Defence Research Establishment (FFI))
Trond Jenserud (Norwegian Defence Research Establishment (FFI))

WATERMARK is a benchmark for testing, development, and comparison of physical-layer schemes for underwater acoustic communications. Its core is a replay channel simulator driven by at-sea measurements of the time-varying impulse response. WATERMARK is programmed in MATLAB and is initially provided with two (single-receiver) test channels with a run time of 30 minutes each. These channels were measured in Norwegian waters in the frequency band from 10 to 18 kHz. The benchmark can be extended with channels from different environments and frequency bands, depending on the willingness of third parties to perform and make available such measurements.

Non-Acoustic Communication Modalities

(Chairs: Brandon Cochenour and Fraser Dalgleish)

Development and Validation of Blue Ray, an Optical Modem for the Medusa class AUVs

Pedro Gois (ISR - Instituto Superior Tecnico, Universidade de Lisboa)
Nichin Sreekantaswamy (ISR - Instituto Superior Tecnico, Universidade de Lisboa)
Nandeesh Basavaraju (ISR - Instituto Superior Tecnico, Universidade de Lisboa)
Manuel Rufino (ISR - Instituto Superior Tecnico, Universidade de Lisboa)
Luis Sebastiao (ISR - Instituto Superior Tecnico, Universidade de Lisboa)
Joao Botelho (ISR - Instituto Superior Tecnico, Universidade de Lisboa)
Joao Gomes (ISR - Instituto Superior Tecnico, Universidade de Lisboa)
Antonio Pascoal (ISR - Instituto Superior Tecnico, Universidade de Lisboa)

Wireless optical communications are emerging as a viable solution for high-speed data transmission over short ranges in the ocean, complementing mainstream acoustic communication systems that operate over much longer ranges, but at lower data rates. The current drive to develop cooperative autonomous vehicular systems to carry out surveying and other complex missions in the ocean critically depends on the existence of such communication links to share sensory and coordination information. This paper presents a compact, low power consumption, cost-efficient, and lightweight optical modem designed for fast data transmission between MEDUSA underwater vehicles at ranges on the order of 10m. The transmitter uses LEDs for ON-OFF keying, while the receiver front-end adopts a transimpedance architecture with a photodiode detector. This simplistic transmission and reception technique reduces the overall design and hardware complexities compared to, e.g., laser diodes and photomultiplier tubes. The LEDs are arranged in a circular array, with a photodiode at the centre to enable half-duplex operation. These modems are designed to achieve data rates of 20 - 200 kb/s over short-range, line-of-sight, configurations. A transparent casing is customised to fit the MEDUSA vehicles, with proper alignment for inter-vehicle communication when they move in formation.

Temporal dispersion in underwater laser communication links: Closing the loop between model and experiment

Brandon Cochenour (Naval Air Warfare Center)
Alan Laux (Naval Air Warfare Center)
Linda Mullen (Naval Air Warfare Center)

An elevated interest in underwater optical communications has resulted in the

development of numerous theoretical models to predict both signal attenuation and bandwidth (pulse spreading) for underwater optical links. Few, if any, of these models have been experimentally validated, owing mostly to the difficulty in experimentally measuring temporal dispersion in these challenging environments. In this work, we begin to close the loop between theory and experiment, by validating a numerical Monte Carlo model against experimental data. Channel attenuation and frequency response is measured out to 1 GHz over 20 attenuation lengths in a line-of-sight configuration.

Experimental testbed for seawater channel characterization

Pablo Mena (Universidad de Las Palmas de Gran Canaria/IDeTIC)
Pablo Dorta (Universidad de Las Palmas de Gran Canaria/IDeTIC)
Gara Quintana (Universidad de Las Palmas de Gran Canaria/IDeTIC)
Ivan Perez-Alvarez (Universidad de Las Palmas de Gran Canaria/IDeTIC)
Eugenio Jimenez Yguacel (Universidad de Las Palmas de Gran Canaria/IDeTIC)
Santiago Zazo (Universidad Politecnica de Madrid/ETSI Telecomunicacion)
Marina Perez (Universidad Politecnica de Madrid/ETSI Telecomunicacion)
Laura Cardona (Oceanic Platform of the Canary Islands (PLOCAN))
J. Joaquin Hernandez (Oceanic Platform of the Canary Islands (PLOCAN))

Shallow seawaters are problematic for acoustic and optical communications. Sensor networks based on electromagnetic (EM) communications are evaluated in this environment. In order to characterize the underwater channel, several measurement systems have been designed, built and tested in the sea obtaining very reliable results. Experiments carried out with dipoles and loop antennas showed serious disagreement with the state of the art, especially when dipole antennas are used. Dipoles performance was poor while magnetic loops showed much lower attenuation. A measurement system is described in detail and real attenuation of the underwater channel is obtained for several distances and antennas. Finally, measured and simulated results are compared and reveal good agreement.

Investigation on Radio Wave Propagation in Shallow Seawater: Simulations and Measurements

Eugenio Jimenez Yguacel (University of Las Palmas de Gran Canaria/IDeTIC)
Gara Quintana (University of Las Palmas de Gran Canaria/IDeTIC)
Pablo Mena (University of Las Palmas de Gran Canaria/IDeTIC)
Pablo Dorta (University of Las Palmas de Gran Canaria/IDeTIC)
Ivan Perez-Alvarez (University of Las Palmas de Gran Canaria/IDeTIC)
Santiago Zazo (Universidad Politecnica de Madrid/ETSI Telecomunicacion)

Marina Perez (Universidad Politecnica de Madrid/ETSI Telecomunicacion)
Eduardo Quevedo (Oceanic Platform of the Canary Islands (PLOCAN))

The authors present full wave simulations and experimental results of propagation of electromagnetic waves in shallow seawaters. Transmitter and reciever antennas are tenturns loops placed on the seabed. Some propagation frameworks are presented and simulated. Finally, simulation results are compared with experimental ones.

OptoCOMM: introducing a new optical underwater wireless communication modem

Andrea Caiti (Department of Information Engineering, University of Pisa)
Ernesto Ciaramella (Scuola Superiore Sant'Anna, Instituto TeCIP)
Giuseppe Conte (Dipartimento di Ingegneria dell'Informazione, Universita´ Politecnica delle Marche)
Giulio Cossu (Scuola Superiore Sant'Anna, Instituto TeCIP)
Daniele Costa (Dipartimento di Ingegneria dell'Informazione, Universita´ Politecnica delle Marche)
Simone Grechi (Department of Information Engineering, University of Pisa)
Roger Nuti (Department of Information Engineering, University of Pisa)
David Scaradozzi (Dipartimento di Ingegneria dell'Informazione, Universita´ Politecnica delle Marche)
Alessandro Sturniolo (Scuola Superiore Sant'Anna, Instituto TeCIP)

OptoCOMM aims at demonstrating the potential, at physical level, of a communication facility for the SUNRISE platform constituted by an Optical Underwater Wireless Communication (OUWC) module with target performance of 10 Mb/s transmission rate at 10 meters range in shallow medium/high turbidity harbour waters. The module, which is based on blue Light Emitting Diode (LED) units and common photodiodes, is an evolution of the proof-of-principle prototype already proven in laboratory (pool). It will constitute an additional node integrated in the Littoral Ocean Observatory Network (LOON) test-bed of the SUNRISE infrastructures, providing a high speed and short-range communication node, which will complete the capability of acoustic modems already present in the test-bed. Three modules (nodes) will be developed and experimentally demonstrated: one for direct integration with the LOON infrastructures, one, battery powered, to be potentially installed on buoys, Remotely Operated Vehicles (ROVs), etc., and one to be installed on the eFolaga Autonomous Underwater Vehicle (AUV) of the proponents. The paper describes in detail the development of the modems as well as the first lab experiments, where the core technology has been successfully tested.

Dipole Antenna for Underwater Radio Communications

Sofia Inácio (INESC TEC)
Mário Pereira (INESC TEC)
Hugo Santos (INESC TEC)
Luís Pessoa (INESC TEC)
Filipe Teixeira (INESC TEC)
Mário Lopes (INESC TEC)
Oluyomi Aboderin (INESC TEC)
Henrique Salgado (INESC TEC)

The radiation characteristics of a dipole antenna when immersed in both fresh and seawater are assessed through simulation and experimental work. Simulations show that the antenna's bandwidth and radiation pattern change with the properties of the medium where it is placed, namely the conductivity of the medium. Two dipoles antennas with current baluns were built and tested experimentally in freshwater. The tests included the measurement of the insertion loss between two identical dipole antennas and their radiation pattern. The results obtained show a good agreement between the simulation and experimental results.

Non-visible light underwater optical communications

Norman Farr (Woods Hole Oceanographic Institution)
Clifford Pontbriand (Woods Hole Oceanographic Institution)
Jonathan Ware (Woods Hole Oceanographic Institution)
Leo-Paul Pelletier (Woods Hole Oceanographic Institution)

One look at the absorption curve for light in water suggests that the best possible window for underwater optical transmission is at the blue-green end of the visible light spectrum, centered at roughly 450 nm for clear, deep water, and shifted more towards green for coastal water. While this holds true for signal transmission in the optical communications channel, it is also true for the solar spectrum, which presents as in-band white noise near the ocean surface. The greatest signal loss and interference is in the 0 to 40 meter depth range, but solar irradiance is still present to a depth of 300 meters and in some cases to a depth of 500 meters.
Because solar radiation shares the same spectral band as the communications signal, solar light is very difficult to reject without the loss of transmitted communications signal. For wide-angle transmitters and receivers, dielectric, thin-film (TF) filters are not effective due to the wavelength dependence on angle of incidence, thus making narrow-angle band pass filters for underwater use very difficult to design. Absorptive filters can be used to reject large portions of the visible spectrum, but the problem of in-band noise still remains since absorptive filters do not exhibit the sharp cutoff of interference

filters.
Sources in the range of 350 to 400 nm present a viable means to work at, or just beyond, the edge of the visible spectrum where a majority of sunlight can be rejected. Until recently, efficient, inexpensive, near ultraviolet (NUV) sources have not been readily available; but the demand for new, high power NUV light-emitting diodes (LEDs) for commercial applications has made their use in underwater applications possible. These wavelengths are not visible to the human eye thus making them good candidates for non-visible communications.
The Woods Hole Oceanographic Institution's (WHOI's) Optical Communications Group has performed many field and lab experiments with short wavelengths for the purpose of wavelength division multiplexing (WDM), enhanced daylight performance, and non-visible underwater communications. Initially 405 nm LEDs were used for WDM in shallow water and then for long-range transmission tests in deep water at the Axial Seamount of the Juan de Fuca Ridge (JDR). Additional tests were performed using 405 nm and 385 nm near the surface at JDR to assess ambient daylight rejection. Recently, work has been done in very shallow water in Cape Cod Bay to assess range with high ambient light in very turbid water.

Architectures and Novel Stacks

(Chairs: Tommaso Melodia and Paolo Casari)

SEANet G3: High-Data-Rate Software-Defined Underwater Acoustic Network Platform
("Off-the-record" paper)

Emrecan Demirors (Northeastern University)
Tommaso Melodia (Northeastern University)

As of today, the underwater acoustic wireless communication platforms are mostly based on inflexible hardware that can support mostly point-to-point, low-data-rate, delay-tolerant applications. Regrettably, these devices do not provide neither the sufficient data rates nor the necessary flexibility to support future underwater networking applications and systems. To that end, we propose a new high-data rate software-defined underwater acoustic networking platform, SEANet G3, with unique characteristics in terms of data rate (megabit/s data rates are foreseen over short range links), spectrum agility, and hardware/software flexibility in support of distributed networked monitoring operations. Moreover, we demonstrate data rates in the order of megabit/s on a controlled lab environment and for the first time data rates of 522 kbit/s in the sea over short horizontal links (e.g. 10m) for a BER lower than 10^{-3}.

The DESERT Underwater Framework v2: Improved Capabilities and Extension Tools

Filippo Campagnaro (University of Padova)
Roberto Francescon (University of Padova)
Federico Favaro (University of Padova)
Federico Guerra (University of Padova)
Paolo Casari (IMDEA Networks Institute)
Roee Diamant (University of Haifa)
Michele Zorzi (University of Padova)

The DESERT Underwater emulation system (http://nautilus.dei.unipd.it/desert-underwater), originally designed for testing underwater acoustic networks, has been recently extended. The new framework now includes multi-modal communication functionalities encompassing low rate and high rate acoustics as well as optics, the capability of testing wireless telemetry for underwater equipment, a connection to the most recent version of the World Ocean Simulation System (WOSS), a modification to the RECORDS system for sea trial remote control, and an interface between external tools, e.g., Matlab, and the EvoLogics modem. In addition, experimental activities are

now supported by an accurate real-time event scheduler which has been shown to support, among others, long experiments involving time-division multiple-access (TDMA)-based MAC protocols. These additional protocol schemes from the MAC to the application layer (most of which have been tested in controlled environments and sea trials) now make DESERT Underwater a comprehensive tool for underwater network simulation and experimentation. In this paper, we present the new functionalities developed over the last two years.

Security in Underwater Communications

(Chairs: Mauro Conti, Gianluca Dinni and Roberto Petroccia)

Secure Underwater Acoustic Networks: Current and Future Research Directions

Chhagan Lal (University of Padova)
Roberto Petroccia (CMRE)
Mauro Conti (University of Padova)
João Alves (CMRE)

Underwater Acoustic Networks (UANs) are widely used in various applications such as climate change monitoring, pollution control and tracking, tactical surveillance and offshore exploration. However, limited consideration is given to the security of such networks, despite the fact that the unique characteristics of UANs make these networks vulnerable to various malicious attacks. In this paper, we address future aspects of how to improve security in UANs. We start by reviewing and discussing the state-of-the-art security threats for underwater networks along with their existing solutions. We then identify the open research issues and challenges in the design of secure protocols for communication in UANs. We propose innovative approaches based on node cooperation, cross-layering, software-defined cognitive networking and context-aware communication in order to effectively provision new or strengthen existing security frameworks in UANs. By using these approaches, we address the problem of detecting malicious behaviours and rogue nodes in order to address the major security issues in UANs. We also investigate the use of a covert channel based detection mechanism which needs to be considered when monitoring or deploying UANs at sea. We believe that the issues raised and future possible solution approaches proposed in this paper will greatly help the researchers contributing towards fortifying security in an inherently in-secure UAN.

Analytical Metric Weight Generation for Multi-Domain Trust in Autonomous Underwater MANETs

Andrew Bolster (University Of Liverpool)
Alan Marshall (University Of Liverpool)

Trust Management Frameworks (TMFs) are being used to improve the efficiency, security, and reliability of de- centralized and distributed autonomous MANETs using metrics garnered from the communications activities of nodes within the networks. However, these do not perform well in sparse / harsh environments such as those

found in Underwater Acoustic Networks (UANs). As node capabilities increase, the physical motion of nodes represent an additional domain of knowledge about the operations and behaviours of the network. In this paper we present a Machine Learning supported methodology for optimising metric weight vector generation, using metrics from both physical and communications domains to detect and identify a range of misbehaviours, demonstrating that by utilising information from multiple domains, trust assessment can be more sensitive and accurate than in single-domain (communications) assessment.