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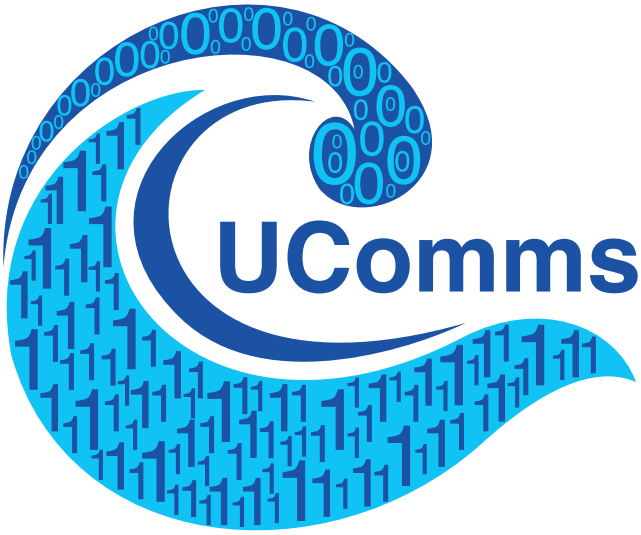

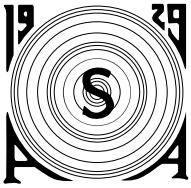

IEEE Oceanic Engineering Society

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Keynote Talk:

Underwater Communications And Networking: Where Do We Go From Here?

By Prof. Mandar Chitre

The last few decades have seen significant advances in underwater communication and networking. Yet, underwater communication technology can be considered far from mature today. There are formidable challenges, no doubt, and we attribute the large performance gap between terrestrial wireless communication and underwater communication to these challenges. While we steadily chip away at the problems, the gains seem to be incremental and the progress slow. Are we close to saturation with the performance underwater communication networks can deliver, or is there a lot more we can do? I believe that there is still much to be done, and much more rapid progress can be made if we had more researchers working on the key problems and building on top of each other's work. We need cooperation between research groups at a level beyond what is widespread today. We need to democratize access to the field so that more people can contribute and increase the chances of disruption. Given limited access to resources needed for at-sea experimentation in a variety of environments, most researchers would greatly benefit from cooperation. Publishing of reproducible results, sharing of code and data, standardized benchmarking scenarios, and standardized channel models are few of the things we should consider embracing as a community. While many of us might agree that this would be a good thing to do, cooperation can be tricky to achieve in practice, as well-known game theory examples such as the prisoner's dilemma demonstrate. We need to reduce the barrier to cooperation and find ways to facilitate and encourage sharing, through the right combination of technology, policy and social change. This has been successfully done in some areas of research. In this talk, we will discuss some strategies and best practices from other fields of research that have helped those fields achieve great synergies between researchers. We will explore if some of these strategies could work for us as a community, and what we need to do if we want to adopt them.

Invited Talk:

Acoustic Communications With Directional Arrays For UUV's

By Prof. Arthur B. Baggeroer

Almost all acomms systems to date use transmitters with little directionality and receivers with omnidirectional hydrophones. The mode of operation is to transmit to a very wide world and listen to

the same. Here, we are focused on the use of directional arrays on UUV's which by in large implies mobile, horizontal arrays. However, vertical arrays may also be part of mission CONOPs. There has been some experiments with directional arrays. The original DATS (Digital Acoustic Telemetry System) had a 4 x 8 element steered phased transmit array operating at high frequencies 40 – 50 kHz. In addition, there have been several efforts using array receivers and recorded received data analyzed offline Song used the FORA (Five Octave Research Array) for very low frequency (< 500 Hz) signals transmitted over several hundred kilometers from a J15/3 source. The KAUAI acomms (KAM11) recorded mid to high frequency (3.5 – 35 kHz) array data. These all demonstrated performance improvements using directionality. In addition, for a complete system and eventual goal there have been a few experiments such as SeaWeb which explored the problems of full duplex moralities which may be considered the eventual goal for an acomms system.

Many concepts of operation now envisioned for UUV's imply connectivity now done with "lightening bolts" on PowerPoint figures. There is an often expressed need for reliable acoustic communications among these UUV's. We suggest that directional systems offer several advantages towards this goal. Directionality provides:

1. a cleaner channel with higher SNR's because it mitigates reverberation and provides array gain;
2. deconfliction among many users of the same time - bandwidth space;
3. an inherent approach to stealth and LPI/LPD by using lower transmit power.

Stealth calls for transmitting signals at a rate and power appropriate for channel capacity between at transmitter and receiver but below the acquisition threshold for an interceptor using incoherent processing and state of art array processing algorithms for detecting directional signals.

If directionality offers so many important advantages, why has it not been used more for acomms. RF communications have employed directionality almost since their inception. The major difficulties are the synchronization/tracking and the long propagation delays. A link must be established among the several platforms with uncertain bearings for steering and ranges for timing. Narrow beams and uncertain timing call for acquisition and link management strategies especially for ARQ needs in the signals. This is all very difficult in a dynamic scenarios with the long time delays for acomms. There are many applications and one can postulate acomms arrays from the very small San Sharks operating at the 50 – 100 kHz at very short ranges to LDUUV's at 500 Hz and very long ranges on the scale of 100 kms. This presentation will cover the advantages and problems which must be surmounted to respond to the need for full duplex reliable and stealthy acomms with UUV platforms.

Technical Session: Applications and Requirements

(Chairs: Henry Dol and Paolo Casari)

Integrated Comunication Network For Underwater Applications: The SWARMs Approach

F. Pacini, G. Paoli, O. Kebkal, V. Kebkal, K. Kebkal, J. Bastos, C. Monteiro, V. Sucasas, B. Schipperijn

The exploitation of marine resources and underwater raw materials and the monitoring of the oceanic environment increases the fields of application of robotic autonomous and manned platforms. The management of heterogeneous mixes of these vehicles needs high performance reliable and robust communication systems able to cover medium-long distances, to assure enough bandwidth to transfer vehicles status data and pictures/videos and to be flexible to adapt the network configuration to the specific scenarios and applications. The challenging conditions of the underwater environment impose several constraints to the available communication systems, so the full network shall be a trade-off between different requirements and performances. This paper describes some new solutions implemented in the ECSEL co-funded European project "Smart and Networking UnderWAter Robots inCooperation Meshes" (SWARMs). The proposed approach is to select, combine and integrate available heterogeneous communication technologies, components and solutions, developing specific adaptations and modifications to improve performances for the remote management and control of swarm of underwater vehicles.

Flying Acoustic Modem: Results And Future Concepts Of Operation

J. Galante, M. Ribeiro, P. Dias, H. Jain, P.b. Sujit, J. Sousa

Results driven AUV operations are complex and when multiple AUVs are deployed, a large number of problems arise. One such problem is the communications between the network of AUVs and the human operators. In this paper, we strive to explore one of the steps taken in order to develop a novel solution to this particular problem.

When an AUV is deployed for a high endurance mission, having it resurface periodically can be a time consuming and hazardous proposition. In one hand there is the need to protect and maintain the mission, while in the other there is the need for the human operator to receive and assimilate data mid-mission.

The Flying Modem is a UAV with water-landing capabilities, that also carries an acoustic modem, effectively becoming a mobile, acoustic to Wi-Fi relay point in the mission network. It allows the AUV to communicate with it and then have the UAV relay the data to base. In the presence of multiple AUVs, the UAV needs to predict their potential location and determine the best route to meet all AUVs. For this paper we developed a path planning technique that ensures that all of the AUVs are visited by the UAV within a given sortie.

Underwater Acoustic Communications for Submarines - A Sonar Company's Perspective

F. Schulz, T. Wiegand

Modern navies increasingly demand to incorporate submerged assets in naval networked operations. Especially the requirement for providing information to submarines operating at speed and depth is pushing digital underwater acoustic communications from research level to commercial products. In order to address these needs, ATLAS ELEKTRONIK GmbH has developed a concept that fully integrates the UW Comms capability in the company's submarine sonar systems.

Self-Synchronization Of Multiple Vehicles` Using Ambient Impulsive Noise

P. Naughton, T. Salam, P. Tueller, P. Roux, C. Schurgers, R. Kastner, J. Jaffe, P. Roberts

Clock synchronization is important when considering a swarm of underwater vehicles. Unfortunately, accurate clocks are expensive, and acoustic communication is power intensive, preventing large numbers of vehicles from being deployed for long periods of time. We propose a technique where vehicles achieve relative synchronization by leveraging sounds already present in the underwater environment. This provides a synchronization method that does not rely on expensive clocks, communication, or additional infrastructure. We demonstrate that our technique accurately tracks clock offsets between vehicles during an at sea deployment.

On The Feasibility Of Video Streaming Through Underwater Acoustic Links

F. Campagnaro, R. Francescon, D. Tronchin, M. Zorzi

Nowadays video IP traffic accounts for 73% of the entire global Internet traffic with forecasts up to 82% by 2021. While live video streaming is already mature through media such as coaxial cables, optical

fibers and radio links, real-time live video streaming through underwater acoustic communication is still in its infancy. The underdevelopment of underwater live streaming is due to both the unstable nature and the long propagation delay of the acoustic channel. The former poses several obstacles to reaching the needed bitrate capabilities, while the latter causes a non-negligible video latency proportional to the distance between transmitter and receiver. Despite these obstacles, a lot of research on advanced video codecs is conducted to reduce the required bitrates of a video stream. In addition, modem manufactures recently developed short range high rate acoustic modems.

This work presents a feasibility study of a live video streaming based on the best performing video codecs (H.264/MPEG-AVC, H.265/MPEG-HEVC and VP9) through current commercial acoustic modems. The feasibility evaluation has been proved with a final pool test, where the video has been successfully streamed with real acoustic modems.

Field Experiments With A Dual-Frequency-Band Underwater Acoustic Network

H. Dol, M. Colin, P. vanWalree, R. Otnes

For remote deployment of unmanned/autonomous underwater vehicles that, for reasons of size, power usage and cost, communicate acoustically in relatively high frequency bands, a backbone underwater acoustic network needs to support multiple frequency bands with the communication streams being able to cross over between bands as required. This paper presents results of successful field experiments with a dual-band underwater acoustic network.

Technical Session: Simulation, Models and Test Beds

(Chairs: Tommaso Melodia and Sérgio Jesus)

NETSIM: A Realtime Virtual Ocean Hardware-in-the-loop Acoustic Modem Network Simulator

T. Schneider, H. Schmidt

This paper presents netsim, a combined software/hardware system for performing realtime realistic operation of autonomous underwater vehicles (AUVs) with acoustic modem telemetry in a virtual ocean environment. The design of the system is flexible to the choice of physical link hardware, allowing for the system to be tested against existing and new modems. Additionally, the virtual ocean channel simulator is designed to perform in real time by coupling less frequent asynchronous queries to high-fidelity models of the ocean environment and acoustic propagation with frequent perturbation-based updates for the exact position of the simulated AUVs. The results demonstrate the performance of this system using the WHOI Micro-Modem 2 hardware in the virtual ocean environment of the Arctic Beaufort Sea around 73 degrees latitude. The acoustic environment in this area has changed dramatically in recent years due to the changing climate.

Phase Estimation Error of a PSK Underwater Acoustic Signal in Presence of Multipath and Volume Scattering

K. Kebkal, A. Mashoshin, S. Yakovlev, O. Kebkal, V. Kebkal

Mathematical approach has been used to model the received phase encoded signal with swept carrier in underwater acoustic medium with multipath and volume scattering. By splitting the mathematical model of the received signal into three components at the receiver's pre-detection point (useful signal, error due to multipath and error due to volume scattering), the influence of each component on the accuracy of the differential phase estimation was evaluated analytically in well controlled propagation medium. The modeling results are consistent with experimental results during deep water trials.

Making The Most Of Field Data To Support Underwater Acoustic Communications R&D

G. Deane, J. Preisig, A. Singer

Field data is often expensive to collect, time-consuming to prepare to collect, and even more time-consuming to process after the experiment has concluded. However, it is often the practice that such data are used for the research activity that was concomitant with the experiment, and then for little else after the funded research activity is completed. This paper discusses useful steps that can be taken to 1) collect sufficient environmental statistics such that subsequent research can be accomplished long after the experiment has completed, and that results from a given experiment may be reasonably compared with those of another, and 2) prepare signals for transmission and subsequent recording such that research trades for different modulation and coding schemes may be undertaken post-experiment, without the need for retransmission of additional waveforms, and 3) creation of an sufficiently meaningful model and collection of sufficient data to enable post-experimental replay of the environment.

Communication Operations at THEMO: the Texas A and M - University of Haifa - Eastern Mediterranean Observatory

R. Diamant, S. Dahan, I. Mardix

We introduce the communication operations of THEMO: the new Texas A&M - University of Haifa - Eastern Mediterranean Marine Observatory. THEMO includes moored sensors, surface sensors, and secondary moorings. In all cases, the data from the sensors is transferred in near real-time to a shore station where it is freely shared with the community. Variety of communication aids are used. These include underwater acoustic communications to connect the sensors onboard the secondary moorings with THEMO's surface platform, underwater inductive communication to connect the moored submerged sensors to the buoy's controller, and radio communication connecting the mooring to the shore station. After deployment of almost a year, our results show that the communication performance are reliable, and the data flows in all weather conditions. In this paper, we describe the mooring's communication applications, and share the details of the different communication components.

Technical Session: Architectures and Novel Stacks

(Chairs: Toby Schneider and Rosa Zheng)

The SEANet Project: Toward a Programmable Internet of Underwater Things

E. Demirors, J. Shi, A. Duong, N. Dave, R. Guida, B. Herrera, F. Pop, G. Chen, C. Casella, A. Tadayon, M. Rinaldi, S. Basagni, M. Stojanovic, T. Melodia

Wirelessly networked systems of underwater devices are becoming the basis of many commercial, scientific, and military applications. In spite of increased attention in the last few years, underwater wireless networking technology still suffers from major limitations, including severe hardware dependence. In this paper, we introduce the SEANet Project, an NSF-funded effort that aims at developing a new generation of programmable platforms and a networking testbed to enable the vision of a programmable Internet of Underwater Things (IoUT). SEANet will be based on new software-defined platforms based on an open architecture to enable the flexibility to define, add, update, and swap new components in both hardware and software. SEANet is designed to support data rates at least one order of magnitude higher than existing commercial platforms over short and moderate range links. Moreover, the SEANet project will explore the design of new custom-designed ultra-wide band Microelectromechanical systems (MEMS) transducers that allow operating over much wider acoustic bandwidth (i.e., 0.01−2MHz) than possible with bulk piezoelectric transducers. We present a set of preliminary experiments showing that SEANet can outperform existing software-defined radio SDR-based acoustic modems based on a commercial off-the-shelf (COTS) SDR platforms. We also demonstrate the real-time reconfiguration capability of SEANet and preliminary performance of the MEMS transducers.

Dflood Network Protocol Over Commercial Modems

R. Otnes, J. Locke, A. Komulainen, S. Blouin, D. Clark, H. Austad, J. Eastwood

This paper presents the integration of the underwater communication network protocol “Dflood”, of the restricted flooding family, over commercial modems from Teledyne Benthos. The network protocol was re-implemented and is running on a separate processor board, communicating with the modem over the serial port. Issues of fragmentation and packet reception errors are handled by a separate framing mechanism between the network layer and the modem. The setup was successfully tested in November 2017 as part of the DUSN (Distributed Underwater Sensor Networks) cooperation project between Canada, Norway, and Sweden. Good network layer performance was achieved in spite of most individual

links having a packet delivery ratio between 0.25 and 0.75. By this work, we show an example of how network protocols from the research community can be run over commercial modems without accessing or modifying the modem firmware.

A Cross-Stack QoS Routing Approach For Underwater Acoustic Sensor Networks

L. Emokpae, Z. Liu, G. Edelmann, M. Younis

In this paper, we utilize a novel cross-stack design that factors in the dynamics of the underwater channel to optimize the single-hop performance amongst multiple node pairs. This will result in a set of links that meet or exceed QoS requirements, which is further leveraged for network discovery and energy-efficient routing with minimum end-to-end packet delay. Thus, our proposed routing approach will provide means to guarantee application-specific QoS while also maximizing the network lifetime. Simulation experiments were conducted to validate the approach in a shallow water multipath environment.

An Acoustically Powered Battery-less Internet of Underwater Things Platform

R. Guida, E. Demirors, N. Dave, J. Rodowicz, T. Melodia

The Internet of Underwater Things (IoUT) is a promising approach to future military, scientific, and commercial applications at sea. Vital components of the IoUT are underwater wireless sensor networks (UWSNs) and autonomous underwater vehicles (AUVs). Powering of these systems in deep water still remains one of the main challenges, since UWSN nodes and AUVs are typically powered by batteries that need to be replaced or recharged through expensive and difficult operations.

This article presents the design of the first batteryless underwater sensor node that can be wirelessly recharged through ultrasonic waves from longer distances than allowed by current inductive and magnetic technologies. First, the architecture of an underwater platform capable of extracting electrical energy from ultrasonic waves is introduced. We then illustrate how to interface this system with an underwater digital communication unit. We discuss the design of a prototype of the proposed architecture where the storage unit is realized with a batch of supercapacitors. We show through experiments that the harvested energy stored in the supercapacitors is sufficient to provide an underwater sensor node with the power necessary to perform a sensing operation and power an acoustic modem for ultrasonic communications.

We evaluate the system performance in terms of wireless power transfer efficiency (PTE). Our system is characterized by a lower electrical-to-radiated power conversion efficiency when compared to other technologies. However, given the reduced attenuation of ultrasonic waves in water, we were able to show that our approach can cover longer distances with less transmission power. Last, we evaluate the operating efficiency that we define as the maximum achievable digital data rate relative to the charging and transmission times.

Technical Session: Communications in Challenging Environments

(Chairs: Grant Deane and Mandar Chitre)

Impact of Persistent Bubbles on Underwater Acoustic Communication

G. Chua, M. Chitre, G. Deane

Although it is well known that bubbles have a strong influence on underwater acoustic propagation, typical acoustic communication channel models ignore the effect of bubbles. The rationale is that bubbles are only persistently present in the upper water column in special environments such as the surf zone. In other environments, one expects that the bubbles injected by episodic events such as passing ships quickly rise to the surface or dissolve and do not have a long term effect on the communication channel. We believe that bubbles have a large influence on acoustic communications in many environments with seemingly low bubble injection rates, as bubbles affecting typical communication frequency bands can persist in the water for long periods of time. Such environments include waters near shipping lanes, coral reefs, or places with strong winds. In this paper, we present a model for the persistence of bubbles, and validate it with controlled measurements in a wind-wave channel. We show that bubbles affecting medium-range communication systems can persist in the water column for many tens of minutes after they are injected. This can result in a significant impact on underwater acoustic communications.

A Modem Design for Underwater Acoustic Networking in the High North

C. Pelekanakis, D. Green, Y. Fountzoulas, S. Fioravanti, J. Alves, S. Blouin

We design a software modem for long range underwater acoustic communications in ice-covered oceans. The modem is equipped with three coded modulation schemes achieving 1.8, 21.4 and 96.2 bps, respectively. In addition, we design a new large-scale underwater channel simulator and test the modem performance in the underwater environment of Baffin Bay. Our analysis shows that ranges of more than 200 km can be achieved during summer months provided that the link exploits the ducted sound propagation. During winter months, however, this performance may not be always possible and multiple hops will be needed to cover the same range. The results presented in this work are the basis for the study of adaptive routing solutions for data delivery in multi-hop networks.

An Adaptive Cross-layer Routing Protocol for Underwater Acoustic Networks

R. Petroccia, C. Pelekanakis, J. Alves, S. Fioravanti, S. Blouin, S. Pecknold

This short paper presents an adaptive cross-layer routing protocol for Underwater Acoustic Networks (UANs). The proposed solution, termed NADIR for Network Aware aDaptIve Routing, is fully distributed and self-adaptive. It supports the use of multiple coded modulation schemes and the usage of cross-layer information to interact with the physical layer. Link quality information is exploited along with energy and topological data in order to select the relay node to use. The protocol performance has been evaluated considering a challenging networking scenario, i.e., a polar environment, with very long propagation delays and a high probability of packet errors. The results show that the use of an adaptive strategy offers better network performance in terms of packet delivery and energy consumption in the presence of unreliable channels.

Technical Session: Interoperability and Standards

(Chairs: Roald Otnes, Paul vanWalree and Dale Green)

Ambiguities In Underwater Acoustic Communications Terminology And Measurement Procedures

P. vanWalree, D. Green, R. Otnes

Well-defined terms and measurement procedures are important for transparency in communication and reproducibility of results. Underwater acoustic communications is a technology and research area populated by people with different backgrounds, using different vocabularies and practices. This paper discusses a few important terms which are known to confuse people.

Technical Session: Physical Layer In Acoustic Communications

(Chairs: James Preisig, Charalampos Tsimenidis and Costas Pelekanakis)

Low-Complexity UAC Modem and Data Packet Structure

Y. Zakharov, F. Yuan, P. Mitchel, N. Morozs, B. Henson, L. Chen, T. Tozer

In underwater acoustic communication (UAC), the propagated signal undergoes severe multipath and Doppler distortions. The high overall complexity of UAC receivers is essentially due the Doppler estimation, channel estimation and equalization techniques required to deal with these effects. In this paper, we propose a novel data packet structure for transmission in underwater acoustic channels. This data structure allows the development of relatively simple estimation and equalization techniques, thus resulting in a low-complexity modem design. The data packet is based on single-carrier modulation with superimposed data and pilot symbols. The pilot symbol sequence is repeated within the packet, thus allowing application of the multi-branch autocorrelation Doppler estimation, possessing a low complexity and high accuracy. The data rate in the packet can easily be adjusted depending on the propagation conditions. The received packet is processed in the frequency domain, thus allowing low-complexity channel estimation and equalization. More specifically, in the example design, the channel estimation is based on local cubic B-splines. The modem has been evaluated using numerical simulation and experiments in a water tank, demonstrating successful performance of our design.

Experimental Evaluation of Uplink Underwater Acoustic Communications in Very High Frequency Massive MIMO System

J. Rudander, P. Orten, T. Husøy, P. vanWalree

Massive-MIMO is a proposed technique for the next generation of mobile communication. Here the number of antennas at the base station outnumbers that of the terminals by orders of magnitude. Theoretical work has shown a large increase in spectral efficiency for both Rayleigh and line-of-sight channels. In this paper we evaluate the massive-MIMO concept for wideband very high frequency underwater acoustic communications. Using 64 hydrophones, we analyze how non-perfect channel estimates and multiuser interference depend on the number of hydrophones. Our results show that in some of the measured channels the output SINR grows in proportion to the number of hydrophones, whereas in other channels it reached a threshold. However the results encourage further research.

Pragmatic Performance Optimization of a Multichannel DFE System for a Wideband 100-kbps 1-km Subsea Acoustic Modem

J. Kusuma, A. Jarrot, A. Gelman, A. Croux, G. Choi

We recently demonstrated a real-time wideband 100 kbps 1 km subsea acoustic modem in a horizontal channel off Falmouth, MA, USA, where we conducted the experiment in collaboration with the Woods Hole Oceanographic Institute. To build a real-time receiver, we must allocate limited computing resources judiciously, such that the performance of the wideband acoustic system is optimized. In this paper, we present a pragmatic performance optimization of the decision-feedback equalization (DFE) system we used, based on the number of input channels, feedforward taps, and feedback taps. This allows us to obtain the best performance using best-in-class recursive least squares (RLS) adaptive filters that require significant computational resources. This optimization gives good guidance to optimize the performance of a real-time system where computing resources are limited.

Detecting OSDM Signals in Sparse Channels and Snapping Shrimp Noise

A. Mahmood, M. Chitre

Orthogonal signal-division multiplexing (OSDM), a multi-carrier scheme, has been suggested to be a viable alternative to orthogonal frequency division multiplexing (OFDM). The former outperforms its counterpart by offering lower peak-to-average power ratio (PAPR) and Doppler resistance for the same time-frequency resource. Consequently, due to the time-varying nature of the underwater acoustic channel, recent works have suggested Doppler-resistant (D-OSDM) to be an attractive solution for the underwater acoustic communication problem. We investigate the performance of D-OSDM in snapping shrimp (impulsive) noise and a sparse channel setup for shallow waters. We further propose to minimize a constrained L1-norm that exploits channel sparsity and is also robust to snapping shrimp noise. The approach is also tested in severely impulsive stationary α-sub-Gaussian noise. Our proposed solution offers significant performance gains over contemporary detection methods and underscores D-OSDM's ability to counter impulsive noise.

Exploitation of Spatial Coherence for Reducing the Complexity of Acoustic OFDM Systems

A. Tadayon, M. Stojanovic

This paper addresses the question as to how to exploit spatial coherence between receiving elements in multichannel multicarrier acoustic communication systems in order to reduce the signal processing complexity without compromising the performance. To answer this question, an adaptive pre-combining method is proposed. Without requiring any a priori knowledge about the spatial distribution of received signals, the method exploits spatial coherence between receive channels by linearly combining them into fewer output channels so as to reduce the number of subsequent channel estimators. The algorithm learns the spatial coherence pattern recursively over the carriers, thus effectively achieving broadband beamforming. The reduced-complexity pre-combining method relies on differentially coherent detection which keeps the receiver complexity at a minimum and requires a very low pilot overhead. Using the experimental data transmitted over a 3-7 km shallow water channel in the 10.5-15.5 kHz acoustic band, we study the system performance in terms of data detection mean squared error (MSE) and show that the receiver equipped with the proposed reduced-complexity pre-combining scheme requires three times fewer channel estimators while achieving the same MSE performance as the full complexity receiver.

Coding for Short Messages in Multipath Underwater Acoustic Communication Channels (off-the-record paper)

M. Behgam, R. Zheng, Z. Liu

This paper applies the full tail-biting (FTB) convolutional codes to short data packets and evaluates their performance in underwater acoustic communication by computer simulation and an ocean experiment. The simulation results for AWGN channels show that the FTB codes achieve the similar bit error rate (BER) performance as the zero-tailing convolutional (ZTC) codes regardless of block lengths, while the direct-truncate convolutional (DTC) codes suffer from BER degradation, especially with short block lengths. Both simulation and ocean experimental results demonstrate that the FTB codes are excellent candidates for underwater acoustic communication systems where short data blocks and strong error correction codes are needed.

Model-based Data-driven Learning Algorithm for Tuning an Underwater Acoustic Link

P. Anjangi, M. Chitre

Underwater acoustic channels are fast varying in both spatial and temporal domain and hence are characterized by non-stationary fading statistics. When the channel statistics change, a modulation scheme designed for a specific fading model will underperform which motivates the need for link tuning algorithms. In order to alleviate this problem, data-driven adaptive modulation techniques are studied previously. Since channel information is unknown, these algorithms solve the explore-exploit dilemma in order to take actions that result in maximizing the average data rate. Channel physics information is often ignored in the design of these algorithms. The information gained through channel physics such as delay spread, coherence time, doppler spread etc. of the channel plays an important role in narrowing down the search space of modulation scheme parameters. However, the channel physics by itself is not sufficient to find a good performing solution. Therefore, we develop a hybrid algorithm which utilizes both, the information gained from channel physics and techniques from data-driven algorithms to solve the explore-exploit dilemma. A simplified Orthogonal Frequency Division Multiplexing (OFDM) system is used to illustrate the concept and its parameters are tuned in an online fashion. In particular, an online learning algorithm is developed to track the goodness of the schemes and a multi-armed bandit like problem is solved for taking decisions sequentially in order to maximize the average data rate of an underwater acoustic (UWA) communication link.

Interpreting Different Features of Shallow Water Acoustic Channels Using Braid Manifolds

A. Sen Gupta, R. McCarthy

We explore different representations of the shallow water acoustic channel using braid manifolds with the objective of interpreting diverse channel phenomena. We propose a novel channel model based on braid manifolds that have the natural ability to detect topologically connected channel features across diverse channel representations in time, delay and their spectral components. We demonstrate the need for different representation domains based on localization goals of channel features across time, frequency and varying degrees of channel sparsity. We also provide a comparison between braid interpretations of the time-varying shallow water acoustic channel across different channel representations based on experimental field data collected in the SPACE08 experiment.

Technical Session: Non-Acoustic Communication Modalities

(Chairs: Brandon Cochenour, Fraser Dalgleish and Norm Farr)

Laser Based Underwater Communication Experiments In The Baltic Sea

T. Scholz

While underwater acoustic communication offers a wide range of applications for command and control links, it is restricted in data rate. When transferring huge amounts of information in underwater networks, e.g. between surface and underwater vehicles or other platforms, the additional use of optical communication techniques can be advantageous. Underwater optical communication is studied at WTD 71 on the basis of a laser communication system using a robust two channel approach with orthogonal polarized laser beams. After a first experiment in a harbor basin 2016, a sea trial was performed October 2017 in the Baltic Sea to analyze system performance and channel characteristics in more detail.

Modeling the Performance of Optical Modems in the DESERT Underwater Network Simulator

A. Signori, F. Campagnaro, M. Zorzi

While in the past decades only low rate acoustic modems were employed for underwater wireless communication, nowadays also high rate optical modems can be used for short range communication, up to a few hundred meters. A key question is what is the expected performance of a modem in a given scenario, in order to predict the coverage range of the system in a network deployment. In the literature, many models have been proposed, but each of them is limited to simulating a particular device or a limited set of scenarios. However, in the last decade, many sea evaluations of optical communications performance in different water conditions have been performed, and many datasets published and presented to the research community. In this paper we collect a database of performance figures of optical modems, including it in the DESERT Underwater network simulator. In addition, we simulate optical communication in a real scenario, thanks to the water measurements retrieved during the ALOMEX'15 NATO cruise.

Scintillations Of RGB Laser Beams In Weak Temperature And Salinity-Induced Oceanic Turbulence

H. Oubei, X. Sun, T. Khee Ng, O. Alkhazragi, M. Alouini, B. S. Oo

Fluctuations in the optical signal intensity, known as scintillations, can severely degrade the performance of underwater wireless optical communication (UWOC) links. Using measurements data, this paper focuses on the variations of scintillations of red, green and blue (RGB) laser beams propagating in various weak turbulent water channels. The results show shorter wavelengths experience higher scintillation under the same turbulence. Moreover, the scintillation index decreases when the channel turbulence is dominated by temperature fluctuation. Furthermore, bit-error-rate (BER), which is a critical communication performance evaluation criterion, is also measured for the green laser under such turbulences. It is found that the turbulent UWOC link can still be retrievable in terms of BER performance when the turbulence is below a certain threshold. A steep increasing in BER occurs after the threshold.

Use of Multi-Spectral High Repetition Rate LED Systems for High Bandwidth Underwater Optical Communications, and Communications to Surface and Aerial Systems

P. McGillivary, V. Chirayath, J. Baghdady

A variety of both existing and developing sensors would benefit from near real time communication of high bandwidth data. To cite just one example, sensors that could more accurately report real-time positions of marine mammals would be useful in reducing whale-ship collisions. Similar considerations are relevant for maritime port and harbor security, including detection and alerts for divers or autonomous underwater vehicles (AUVs) that could pose a risk to ships. Especially in ports and harbors, field experiments have confirmed that acoustic communication in these cluttered and noisy shallow water environments, compounded with vertical reflecting surfaces formed by piers and pilings, can limit the reliability and utility of underwater acoustic communications. Moreover, many sensors have greater bandwidth requirements than acoustic communications are able to provide. We here discuss the development of high repetition rate multispectral LED optical systems initially developed for imaging, but also capable of simultaneous data transmission at rates of ~100 kbps. Results are discussed for the multispectral images from coral reefs in Guam, and data transmission experiments from underwater to surface vessels. Subsequent field efforts will extend data transmission from AUVs to unmanned aircraft systems (UAS).

A Study of Modulation Formats for the Blue Ray Underwater Optical Modem

E. Herji, P. André, J. Gomes, P. Góis, A. Pascoal

The transition from acoustic to underwater optical communication links poses many constraints in terms of the maximum link distance, since the latter can only be used in very short-range communications (<0.1 km). Despite this fact, visible light communication systems represent a disruptive change for Autonomous Underwater Vehicles and/or underwater sensor networks, allowing for much higher data rates than those achievable with acoustic links. Blue Ray is a compact, low power, inexpensive, and lightweight optical modem designed for fast data transmission between MEDUSA underwater vehicles at ranges of up to 15 m in clear water. The original design uses On-Off Keying (OOK) at the physical level, with data rates of 20-200 kb/s over short-range, line-of-sight, configurations. The present work examines alternative modulation formats – Pulse Amplitude Modulation (PAM), Pulse Position Modulation (PPM), and Pulse Width Modulation (PWM) –, which can be implemented in the existing hardware of Blue Ray and potentially yield improved rates or robustness. The results of simulations and real-world testing under controlled conditions show that, from all the studied modulation techniques, PPM is generally more power efficient, maximizes the signal-to-noise ratio, and has a higher average bitrate than OOK (for the same achievable Bit Error Rate), despite the lower spectral modulation efficiency. Very good agreement is found between theoretical predictions and the optical modem's experimental performance.

Technical Session: Networking, Localisation and Scheduling

(Chairs: João Gomes, Andrea Munafò and Roberto Petroccia)

Unsynchronized Dual-Hop Scheduling for Practical Data Gathering in Underwater Sensor Networks

N. Morozs, P. Mitchell, Y. Zakharov

In this paper, we propose a centralized dual-hop scheduling approach for efficient and practical data gathering in underwater acoustic sensor networks - Sequential Dual-Hop Transmit Delay Allocation MAC (SDH-TDA-MAC). The practical advantages of this approach include scalability to large networks, little control overhead, no requirement for clock synchronization and low energy consumption and computational complexity. BELLHOP-based simulations reveal that our proposed protocol can achieve full network connectivity with 15 dB lower transmit power, compared with standard single-hop TDA-MAC, while still achieving network throughput in excess of 50% of the theoretical maximum. Furthermore, a comparison with sequential polling show that our proposed protocol can facilitate multiple times faster data gathering by utilizing TDA-MAC for all many-to-one connections at the surface gateway and relay nodes.

Energy-efficient Wireless Analog Sensing for Persistent Underwater Environmental Monitoring

V. Sadhu, S. Devaraj, D. Pompili

The design of sensors or “things” as part of the new Internet of Underwater Things (IoUTs) paradigm comes with multiple challenges including limited battery capacity, not polluting the water body, and the ability to track continuously phenomena with high temporal/spatial variability. We claim that traditional digital sensors are incapable to meet these demands because of their high power consumption, high complexity (cost), and the use of non-biodegradable materials. To address the above challenges, we propose a novel architecture consisting of a sensing substrate of dense analog biodegradable sensors over which lies the traditional Wireless Sensor Network (WSN). The substrate analog biodegradable sensors perform Shannon mapping (a data-compression technique) using just a single Field Effect Transistor (FET) without the need for power-hungry Analog-to-Digital Converters (ADCs) resulting in much lower power consumption, complexity, and the ability to be powered using only sustainable energy-harvesting techniques. A novel and efficient decoding technique is also presented. Both encoding/decoding techniques have been verified via Spice and MATLAB simulations accounting for underwater acoustic channel variations.

Q-Learning Based Adaptive Channel Selection for Underwater Sensors Networks

A. Pottier, P. Mitchell, F. Socheleau, C. Laot

In this paper, we provide self-configuration and adaptation capabilities to UWSN thanks to Q-learning. UWSN deployed for the long term over large areas for environmental monitoring are possible applications of our work. Sensor nodes deployed on the sea bottom are devoted to measure a physical quantity of interest transmitted to surface buoys considered as access points. Packet transmission are asynchronous and low overheads are desirable so as to save throughput and battery life. Prior to a transmission, the nodes choose, depending on the channel conditions, which access point maximizes the probability of successful decoding a the receiver side. Results show that Q-learning is able to perform close to an ideal "genie-aided" scheme, without the need of a detailed knowledge on the environment.

Belief Propagation Based Multi-AUV Cooperative Localization in Anchor-free Environments

Y. Li, Y. Wang, X. Guan

The localization of autonomous underwater vehicles (AUVs) has been a difficult yet fundamental issue in many applications. The traditional way to localize an AUV is based on dead-reckoning (DR) using the measurements from inertial measurement units (IMUs). However, the accuracy of DR cannot be guaranteed for a long period. With the development of underwater communications and ranging, recent AUVs can localize themselves by sharing position information with anchors (whose positions are known). Occasionally, we have to localize an AUV in anchor-free environments. Without reference positions, localization could be challenging. Recently, multiple-AUV (multi-AUV) simultaneous navigation is becoming a prevalent trend and cooperative localization becomes a new way to improve the localization accuracy. In this paper, aiming at anchor-free scenarios, we propose a novel cooperative localization algorithm using belief propagation (BP), called belief propagation based dead-reckoning (BPDR). Meanwhile, to reduce the communication overhead among AUVs, intermittent BPDR (IBPDR) algorithm is designed. The simulations show satisfactory performance in localization by both BPDR and IBPDR.

Parameter-Free Network Localization For Mobile Vehicles, By Learning From Data

C. Soares, J. Gomes

For any operation involving autonomous vehicles, localization of mobile agents is a critical module. Unfortunately, localization methods are still dependent on tweaked parameters, under assumptions of

poor trajectories, and that can fail disgracefully under real-world conditions. As our systems evolve to deployment-ready state, we see the looming need for more adaptive responses, where sudden changes of conditions can be accommodated by the localization algorithm. This paper addresses this gap, by proposing a parameter self-tuning scheme based on learning from acquired data.

Collaborative Hybrid ARQ for CDMA-based Reliable Underwater Acoustic Communications

M. Rahmati, D. Pompili, R. Petroccia

Achieving high throughput and reliability in underwater acoustic networks is a challenging task due to the bandwidth-limited and unpredictable nature of the channel. In a multi-node structure, such as in the Internet of Underwater Things (IoUT), the efficiency of links varies dynamically because of the channel variations. When the channel is not in good condition, e.g., when in deep fade, channel-coding techniques fail to deliver the required information even with multiple rounds of retransmissions. An efficient and agile collaborative strategy among the nodes is required to assign appropriate resources to each link based on their status and capability. Hence, a cross-layer collaborative strategy is introduced to increase the throughput of the network by allocating unequal share of system resources to different nodes/links. The proposed solution adjusts the physical- and link-layer parameters in a collaborative manner for a Code Division Multiple Access (CDMA)-based underwater network. An adaptive Hybrid Automatic Repeat Request (HARQ) solution is employed to guarantee reliable communications against errors in poor communication links. Results are being validated using data collected from the LOON underwater testbed, which is hosted by the NATO STO Centre for Maritime Research and Experimentation (CMRE) in La Spezia, Italy.