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Underwater Acoustic Communications

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Introduction

- Underwater acoustic communications technology has become a ubiquitous part of undersea operations. Oil and gas industry, military, fishing industry, as well as scientific and recreational communities use underwater acoustic modems produced by a well-established industry. Underwater acoustic modems are routinely used to communicate with submarines, Unmanned Underwater Vehicles (UUV), sensor nodes (Ribeiro et al.; 2012) and divers, to name a few examples. The scientific community has also looked into acoustic methods to communicate with marine mammals. Biomimetic technology has also been explored to reach new levels of performance and covertness (Liu et al., 2012). Some recent developments show that an acoustic modem buried in sediment can communicate with an acoustic modem in the water column (Zajic et al., 2013).
- In many ways, the field of underwater acoustic communications has matured. Over the years, the user community has come to realize that: (1) underwater acoustic modems cannot perform evenly in every possible situation; (2) different types of underwater acoustic modem are best suited for different types of operations and environments; (3) the user must carefully select the type and amount of information transmitted prior to any operation, as underwater acoustic modems have limited bandwidth and occasionally fail to transmit information.
- There have been numerous publications and conferences reviewing the state-of-the-art in underwater acoustic communications in the past 30 years, showing the evolution of this technology (Catipovic, 1990; Kilfoyle, 1999; Potter, 2013), including two "State of Technology Reviews" in this Journal (Stojanovic and Freitag, 2013; Chitre et al., 2008).

Introduction

Today, the underwater acoustic communication community is evolving in new ways, for reasons mainly associated with cost, performance and data transfer reliability. Recently, Stojanovic and Beaujean published a textbook chapter on underwater acoustic communication technology (Stojanovic and Beaujean, 2015). In reviewing the many aspects of underwater acoustic communications since World War II, it became clear that:

- The lion share of academic innovation lies in underwater acoustic networking and, to a lesser extent, in improvements to point-to-point communications.
- Despite efforts by part of the community to agree on a standard and a common language that would allow various underwater acoustic modems to interoperate (Stokey et al., 2005), there is very limited interoperability between underwater acoustic modems competing commercially.
- In addition, as assured communications is becoming ever more critical, underwater acoustic modems are becoming an integral part of a larger scheme of wireless underwater communications technology using optics (Dalgleish et al., 2010; Simpson et al. 2012), magnetics (Domingo, 2012; Gulbahar et al. 2012) and acoustics.
- Underwater acoustic modems are increasingly becoming an integral part of a sensor package. For example, an increasing number of Acoustic Doppler Current Profiler (ADCP) come with optional underwater acoustic communications capability. In addition, they are also used as navigation tools (Maki et al., 2013; Schneider et al., 2013) and in conjunction with traditional underwater acoustic positioning.

Trends in point-to-point underwater acoustic communications

There is still a significant gap between technologies developed in research laboratories and commercially available units. This is encouraging, as it indicates that research in underwater acoustic communications remains healthy and innovative.

- In terms of signal modulation, Orthogonal Frequency Division Multiplexing (OFDM) has been the focus of many studies and technological developments (Tu et al., 2013; Wang, L. et al., 2012; Wang, Z. et al., 2012). OFDM is especially promising for its robustness against acoustic reverberation combined with good bandwidth efficiency. In addition, innovative biomimetic signaling has been explored (Liu et al., 2012), which could lead to a new generation of power efficient and covert underwater acoustic technology. New research has also been published in broadband transduction and broadband signal equalization to achieve very high bit rates (Beaujean et al., 2009; van Walree et al., 2013).
- Interference cancellation and noise rejection remains a major problem in underwater acoustic communications, Novel signal equalization techniques have been developed to improve the effective throughput of underwater acoustic modems (Karasalo et al., 2013; Pelekanakis et al., 2013; Song, 2012; Song et al., 2013; Xu, X. et al., 2013; Ling et al., 2012). Also, innovative use of directional transducers lead to significant improvements in communication performance (Chen, 2013; Freeman et al., 2015; Kim et al., 2012; He et al., 2012).
- Finally, Multiple-Input Multiple-Output (MIMO) underwater acoustic communications technology continues to show promise (Kim et al., 2012; Real et al., 2013; Kaddouri et al., 2014). The concept, originally developed in the nineties, consists in simultaneously transmitting different messages from individual acoustic sources to multiple receivers. The individual messages are recovered by jointly processing the received signals. In doing so, the data throughput can increase by several folds. The great difficulty in MIMO technology remains its complexity and cost of implementation.

Trends in underwater acoustic networking

Underwater acoustic networking has become a very active field of research. For example, the Seaweb underwater acoustic network has led to numerous technological advances over the years (Rice, 2008). The growing interest in underwater acoustic networking is due in part to the maturity of point-to-point communication technologies, and also because point-to-point communications performance is gradually approaching the theoretical bound set by bandwidth limitation and speed of sound. In the recent years, many aspects of underwater acoustic networks have been researched:

- Communication protocols (Azad et al., 2013; Ng et al., 2013; Diamant et al., 2013) and packet size optimization (Basagni et al., 2012), which are key elements in optimizing data throughput and power consumption.
- When direct point-to-point communication between two nodes cannot be achieved, routing of information become necessary. Routing is a complicated task in underwater acoustic network, due to the limited bandwidth of underwater acoustic modems and occasional transmission failures. The design and performance evaluation of such routing algorithms has become a field of specialty of its own (Tomasi, 2013; Carlson et al., 2012).
- The actual underwater acoustic network architecture is a critical component of the network performance, both in terms of software (Ojha et al., 2013) and spatial configuration (Marinakis et al., 2012; Detweiler et al., 2012; Liao et al., 2012).
- Network performance evaluation (Caiti et al., 2013) is an important factor in the design of underwater sensor networks. Complete simulation suites now exist to simulate and optimize such networks (Casari, 2014; Petrioli, 2014).

Trends in underwater acoustic networking and Conclusion

- Slow user access and lagging response are common problems in underwater acoustic networks (Chitre et al., 2012; Zhou et al., 2012). To tackle these issues, new research has been published in asynchronous multiuser access (Cho et al., 2012; Wang, Z. et al., 2013; Wang, P. et al., 2013), delay optimization (Chitre et al., 2012; Zhou et al., 2012), time synchronization (Liu et al., 2013) and node adaptability (Wu et al., 2012).
- As power storage is limited, minimization of power consumption can be factored in the design of the acoustic network (Xu, J. et al, 2012). In addition, the concept of remotely powered underwater acoustic sensor networks, which harvest energy from sound, is now investigated (Bereketli et al., 2012).

Conclusion:

In reviewing the latest work from the academia, it clearly appears that underwater acoustic communication technology is still evolving at a rapid pace, especially in the field of underwater acoustic networking and, to a lesser extent, in point-to-point communications. In particular, the research community is developing new tools designed to find a balance between the power consumption of the overall network and the data throughput.

Hermes

- Hermes is a two-way half-duplex underwater acoustic modem developed to transfer large amounts of information from an underwater asset to a surface operator, while being able to send command-and-control information to the underwater asset.
- This communication system must operate in very challenging environments such as busy ports and very shallow waters.
- High bit rate uplink:
  - Omni-directional, 262-380 kHz, max SL 186 dB, max. rate 87768 bps (BER: 10^{-4}).
  - High power transducer (SL 186 dB): 180 m range (field-tested).
  - Low power transducer (SL 180 dB): 135 m range (field-tested).
  - Extended range and spatial diversity capability using High-frequency Gateway Buoys.
- Command-and-control downlink at up to 4223 bps (62-89 kHz, max SL 185 dB).
- Doppler tolerance ±2 m/s.
- Omni-directional transducers are used. “Line-of-Sight” is preferred.
- Platforms: Bluefin HAUV, LM Cetus-II, WHOI Remus-100.
- Technical collaboration with EdgeTech-ORE.

Hermes

- Topside receiver case and High-Frequency Acoustic Gateway (HAG) buoy (left).
- Hermes module for Bluefin Robotics HULS-3 (top center) and Remus-100 (bottom center).
- Bluefin HULS-3 (top right) and Remus-100 Gudgeon (bottom right), equipped with Hermes.

- Battery powered Hermes topside unit tested in Battleship Cove in December 2010.

Achievements

Hermes uplink transmission capability (field-tested):

- Full-resolution DIDSON sonar images containing Seebyte ATR results, mosaic and HULS-3 vehicle status information simultaneously.
- Seebyte 3-D mosaics and vehicle status information simultaneously. The images originate from a DIDSON unit installed on HULS-3.
- Full-resolution Blueview sonar images and operate from a Remus-100 vehicle (this feature still needs need some work).
- Full-resolution or compressed DIDSON images.
- High-resolution JPEG images.
- Closed-loop communications using the command-and-control acoustic downlink.

Product name	**Max Bit rate**	**Range (m)**	**Fmin (kHz)**	**Fmax (kHz)**
Benthos ATM-886	15360	2000	16	21
WHOI Micromodem 1	5400	3000	22.5	27.5
Linkquest UWM 1000	7000	1200	27	45
Evologics S2C R 48/78	31200	2000	48	78
Sercel MATS	28500	4000	30	38
FAU Hermes	87768	180	262	375

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