Smart Acoustic Network Using Combined Fsk-Psk, Adaptive Beamforming and Equalization

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LONG-TERM GOALS

Our long-term objective is a smart acoustic network for multiple underwater vehicle operation, with integrated communication and positioning capability. To do so, a new generation of Coherent Path Beamformer would act as a network decoder and arbitrator for data communication and long (short) base line. Also, wireless communication to shore would be available for control and real-time data transfer. Finally, the underwater vehicles will be carrying an improved version of the compact low-cost Acoustic Modem. This concept requires the network to be synchronous. The concept is to make the most efficient use of time and frequency band.

OBJECTIVES

The smart acoustic network is a multiple-layer system that achieves distinct tasks. As a result, our research effort has been divided into three main projects:
1. High-speed acoustic communication using a High Performance Acoustic Link (FAU-HPAL, Figure 1), also know as “Mills-Cross”.
2. High-reliability acoustic network using multiple General Purpose Acoustic Modems (FAU-GPAM, Figure 2), with a monitoring option using the FAU-HPAL.
3. Development of a Dual-Purpose navigation/telemetry Acoustic Modem (FAU-DPAM, Fig. 3).

The objectives for the high-speed acoustic communication project, using a High-Performance Acoustic Link (FAU-HPAL), are as follow:
1. Setup real-time signal processing software and hardware development and testing for the FAU-HPAL communication system (MillsCross).
2. Upgrade current FAU-GPAM software/hardware for optimal high and low-speed communication.
3. Achieve high-rate video and sonar data transmission from underwater vehicle during mission.

The objectives for the high-reliability acoustic network using multiple General-Purpose Acoustic Modems (FAU-GPAM), with a monitoring option using the FAU-HPAL, are as follow:

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14. ABSTRACT
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15. SUBJECT TERMS

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1. Achieve reliable communication with the current FAU-GPAM generation in underwater vehicle conditions of operations (2000 meters max, mode 4 dual Viterbi/BCH or Reed-Solomon).
2. Design the third generation of FAU-GPAM with the following features:
a) Smaller size and average power use, better multiple ADC/DAC, low electrical noise, Ethernet.
b) New transducer with broader frequency band for multiple mode support.
c) Multiple receivers for channel diversity.
d) Greater processing power, improved multi-channel signal processing.
3. Monitor the underwater vehicle network using FAU-HPAL in FSK mode.

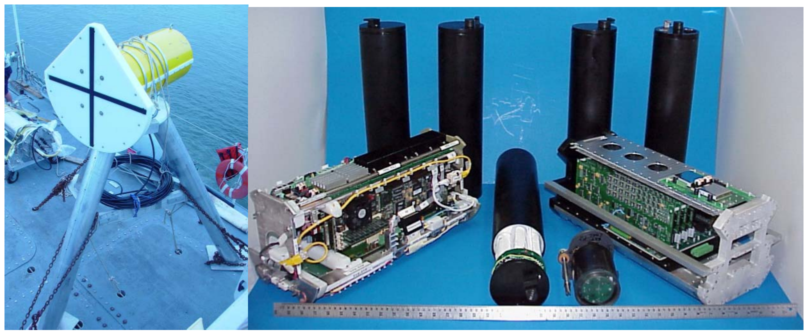

Figure 1. FAU High-Performance Acoustic Link (FAU-HPAL or "MillsCross")

Figure 2. General Purpose Acoustic Modem (GPAM) and Aries UUV Platform

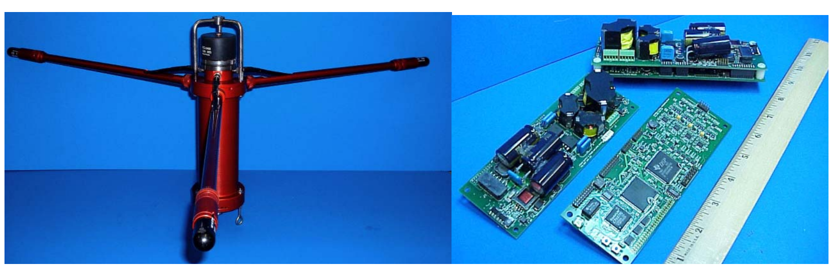

Figure 3. Dual Purpose Acoustic Modem (DPAM) and Embedded Electronics

APPROACH

High-Speed Acoustic Communication using FAU-HPAL:
A high performance acoustic link called the FAU-HPAL has been developed, using a multi-element receiver array that provides 64 individual signals to a high-resolution analog-to-digital converter and digital storage system [3-7]. The source is the FAU General Purpose Acoustic Modem (FAU-GPAM)

developed at FAU (sonar laboratory) and used for acoustic networking during underwater vehicle operation. The joint adaptive coherent path beamformer method consists in splitting the space and time processing into two separate sub-optimal processes. As a result, processing complexity is significantly reduced and the instabilities associated with large tap vectors at large time-frequency spread products are reduced. This method utilizes a different beamformer optimization strategy compared to the time domain optimization strategy, and allows to separately adjust the adaptation parameters for the spatial and temporal characteristics of the signal, which have vastly different requirements. The time domain signal is subject to variations in phase that require rapid filter updates whereas the directional characteristics of the signal do not vary appreciable over the message length and do not require a rapid adaptation response. This method allows for high-speed underwater acoustic communication in very shallow water using coherent modulation techniques, and offers a series of unique features: significant reduction of the signal-to-noise and interference ratio (SNIR), improvement of the bandwidth efficiency by reduction of the forward-error coding redundancy requirements and real-time evaluation of the time-spread by Doppler-spread product (BL).

Acoustic Network using multiple FAU-GPAM and FAU-HPAL Monitoring:

The FAU-GPAM is a high reliability shallow water acoustic modem developed for communication between underwater vehicle and general oceanographic use [1-2]. The modem uses 56 narrow band chirp FM pulses, each centered at a unique frequency located in the range of 16 kHz to 32 kHz. Data rates vary from 221 data bits per second to 1172 data bits per second, depending on the mode of transmission. Packets of information are synchronized using an adjustable number of chirp pulses in a known frequency hop pattern, followed by transmission format information and data. An "auto-baud" mode uses information garnered from previous transmissions for adaptation of the bit rate to the acoustic environment. At the lowest rate, a four-time slot frequency hop pattern is used to provide maximum immunity to multipath interference. The modem is capable of using both half rate convolutional and BCH encoding in order to maximize error resilience. As a first step toward monitoring of the acoustic network using the FAU-HPAL, a multiple-channel signal-processing algorithm has been developed to decode frequency-hopped frequency-shift-keyed (FH-MFSK) FAU-GPAM signals acquired by the MillsCross receiver.

Dual-Purpose Acoustic Modem for Telemetry and Synchronous Navigation

The FAU-DPAM is a high reliability shallow water acoustic modem developed for communication between underwater vehicle and general oceanographic use. FAU-DPAM underwater acoustic modem is the second generation of modems developed at Florida Atlantic University [1-2]. This new modem is being developed to meet current and future requirements in the underwater communications and underwater vehicle fields. The modem provides a robust communications system as well as a versatile platform for research and development of new underwater acoustics and communications techniques. The acoustic modem provides a wireless underwater communications link in the frequency band of 15 to 35 kHz. The host processor handles message traffic to and from the user, formats data to and from the digital signal processor (DSP), time tags incoming and outgoing messages and manages various system resources. The digital signal processor modulates/demodulates messages in the communication channel and manages channel access. The power amplifier drives a broadband communications transducer, while the low noise preamplifier conditions received signals for analog to digital conversion. External user RS232/RS422 serial and 10Base-T Ethernet interfaces are available for host processor communications. Additionally, the host processor address/data bus, host processor SPI serial bus, and DSP multi-channel buffered serial port are available to external devices. The host processor enables the user to easily reconfigure the modem for different communication needs while a powerful fixed point DSP (160 MIPS) allows the implementation of sophisticated encoding/decoding schemes.

WORK COMPLETED

FAU Dual Purpose Acoustic Modem:

1) Testing of the units in communication mode, off the costs of Fort Lauderdale at ranges up to 3 km.
2) Development of a real-time Ultra-Short Baseline (USBL) real-time code to estimate the source location in real-time using the FAU-DPAM. This is a preliminary step toward an optimized real-time code allowing for combined inverted USBL and coherent demodulation of acoustic messages.

High-Speed Acoustic Communication using FAU-HPAL:

1) Development of a more bandwidth-efficient PSK encoding technique based on raised-cosine pulse shaping and implementation of the code on the new FAU-DPAM. Presently, the FAU-DPAM can only be used as a source in PSK mode.
2) Implementation of an optimized C version of the joint adaptive coherent path beamformer processing technique for near real-time data processing of PSK sequences.

Acoustic Network using multiple FAU-GPAM and FAU-HPAL Monitoring:

Development of a new adaptive demodulation technique using a reduced number of receivers. This technique is to be implemented on the 4-channel FAU-DPAM to improve the overall data rate and power consumption. The technique has been developed using data collected by the FAU-HPAL while monitoring two FAU-GPAM acoustic communication using boat platform off Fort Lauderdale, at a maximum range of 5 km.

High-Speed Acoustic Communication between a UUV and the FAU-HPAL:

Development of a new signal processing technique to decode synchronous communication and navigation messages, and estimate the location of the source using the FAU-HPAL. The objective of this mission was to transmit canned side-scan image snippets (6 kbytes each) from a UUV to the HPAL (Figure 4). The collected data have not been processed at the time of this report.

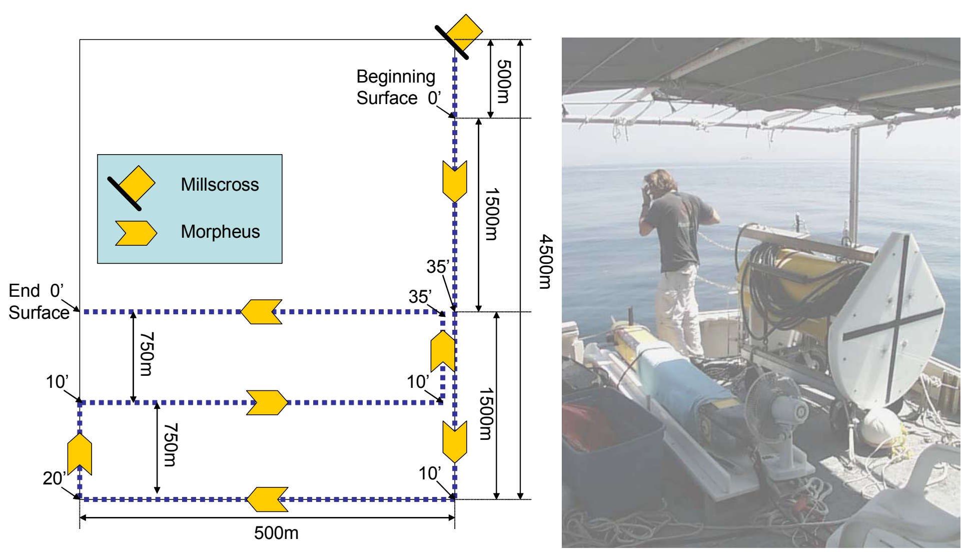

Figure 4. High-Speed Data Transmission from a Morpheus UUV to the HPAL.

RESULTS

High-speed acoustic communication using FAU-HPAL:

1) Using this multiple-stage method, bit rates of 32000 bps can be achieved over 3000 meters range. Better reliability is expected with the new hardware at this rate.
2) Practical rates of 8000 bps to 16000 bps are achieved with high reliability using current hardware.
3) Experimental data collected half-mile off Port Everglades using FAU-HPAL and FAU-GPAM:
a) up to 3.5km range, 20'to 40' water depth, Sand and Reef Bottom
b) 0 to 3 knots source speed, Reverberation Time over 20 ms
4) Fast and slow fading properties of the channel are measured, as the BL product can vary by a decade in 116 ms, and by two decades within minutes, from 0.001 to 0.1. The real-time analysis shows a strong correlation between time spread, Doppler spread, spatial coherence of the acoustic channel and communication performance. The high-speed communications research also provides more scientific and experimental ground to understand the limitations of multi-channel adaptive receiver techniques in terms of stability, hardware requirements and channel tracking capability.

Acoustic Network using multiple FAU-GPAM and FAU-HPAL Monitoring:

A new multi-channel spatial diversity technique has been developed for underwater acoustic communications in very shallow waters [1]. This technique combines a novel synchronization method with maximum-likelihood symbol estimation. It was tested with a multi-channel Mills-Cross receiver using various numbers of elements. The FAU General Purpose Acoustic Modem source transmitted messages using 4 types of frequency-hopped multiple-frequency-chirp-keying (FH-MFSK) modulation: 4 hops at 221 coded bits per second (cps), 2 hops at 442cps, or no hopping at 1172cps. These types of modulation allowed for robust data transmission in adverse environment. The modem operated between 16 kHz and 32 kHz at 192dB of source level, at ranges from 1 to 5 km in 40 feet of water. Using only 4 channels of the Mills-Cross receiver array, messages coded at 1172cps were received with a Frame Error Rate (FER) of 0% at a range of 3 km. In the same 4-channel configuration, messages coded at 221cps were received with no frame error at 5 km. This reliable and computation-efficient method can be implemented on new generations of embedded acoustic modems, such as the 4-channel FAU acoustic modem, and can provide significant improvements in communication performance.

IMPACT/APPLICATIONS

Experimental results are providing a new insight to the understanding of how shallow water propagation conditions affect the information capacity of digital data transmission for sonar operating in the frequency range of 25 kHz.

TRANSITIONS

The technology developed for the DPAM has been disclosed. FAU and EdgeTech Inc. are currently working on transitioning this technology to the industry.

RELATED PROJECTS

"Development of a Synchronous High-Speed Acoustic Communication and Navigation System for Unmanned Underwater Vehicles", Dr. P-P. Beaujean (PI), Dr. Steven G. Schock (Co-PI) and Dr. A.

Folleco (Co-PI). Sponsored by the Office of Naval Research (Dr. T. Swean). ONR award no. N00014-96-1-5031.
"FY02 South Florida Ocean Measurement Center Proposal, Acoustic Gateway", Dr. P-P. Beaujean (PI), Dr. E. An (Co-PI) and Dr. A. Folleco. Sponsored by the Office of Naval Research (Dr. T. Swean). ONR award no. N00014-98-1-0861.

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PUBLICATIONS

Pierre-Philippe J. Beaujean, E.P. Bernault, "A New Multi-Channel Spatial Diversity Technique for Long Range Acoustic Communications in Shallow Water", 1st Pan-Am./Iberian Mtg on Acoustics, Ac. Soc. of Am., Cancun, Mexico, Dec. 2002.