SignalEx: Relating the Channel to Modem Performance

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LONG-TERM GOALS

To understand how the ocean-channel affects acoustic communications, thereby develop tools to predict system performance, and produce a channel-adaptive signaling scheme for optimal communications.

OBJECTIVES/BACKGROUND

The objective of the SignalEx tests is to develop insights about how different environmental conditions affect different signaling schemes. A compelling example of this was provided by the Front engineering test in which network outages were strongly correlated with periods of increase wind speed. High winds generate significant ambient noise while also reducing the reflectivity of the ocean surface, which affects the modems on both sides of the Signal-to-Noise ratio.

This however is just the simplest of mechanisms and different modem schemes may be sensitive to different features such as Doppler shift and spread, multipath spread, multipath sparsity, and rate of variation of the multipath structure. These features in turn depend in a subtle way on the environmental conditions. For instance, the strong sensitivity to wind conditions during the Front engineering test is partly a consequence of the upward refracting conditions which made all acoustic paths interact with the surface.

APPROACH

We have adopted a two-pronged approach in which we independently field our own signaling schemes, yet also kept the experiments open to virtually any participant that have a scheme to test. The list of participants is shown in Table 1. Currently, the internally fielded schemes are a ‘research type-a’, a type-x, and a PPM system. The type-a signaling scheme is a simple FSK approach with several channel-coding options and is virtually identical to the Benthos/Datasonics system. The type-x system is a classical DSSS (Direct-sequence, Spread-Spectrum) method using DPSK and a RAKE receiver not

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14. ABSTRACT
To understand how the ocean-channel affects acoustic communications, thereby develop tools to predict system performance, and produce a channel-adaptive signaling scheme for optimal communications.

15. SUBJECT TERMS

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too different from the IS95 standard developed by Qualcomm. The code was originally developed by NEU (Proakis and Sozer).

Table I: Waveforms tested in SignalEx.

SPAWAR type designation	Method	Analysis group
A	Multi-frequency shift keyed (MFSK)	SAIC/SPAWARSSC
B	Frequency-Hopped FSK (FH-MFSK)	Benthos
	Time-reversal	Naval Postgraduate School
X	Differential phase-shift keyed (DPSK)	Northeastern Univ. SAIC/SPAWARSSC
D	N-QAM (BPSK, QPSK, 16-QAM)	Northeastern Univ., Delphi, NUWC, Benthos
E	Pulse-Position Modulation (PPM)	SAIC
G	Orthogonal Frequency Division Multiplexing (OFDM)	Polytechnic Univ.
H	Multi-Carrier Code Division Multiple Access (MC-CDMA)	Polytechnic Univ.
	Biologic FSK	SPAWARSSC/SAIC

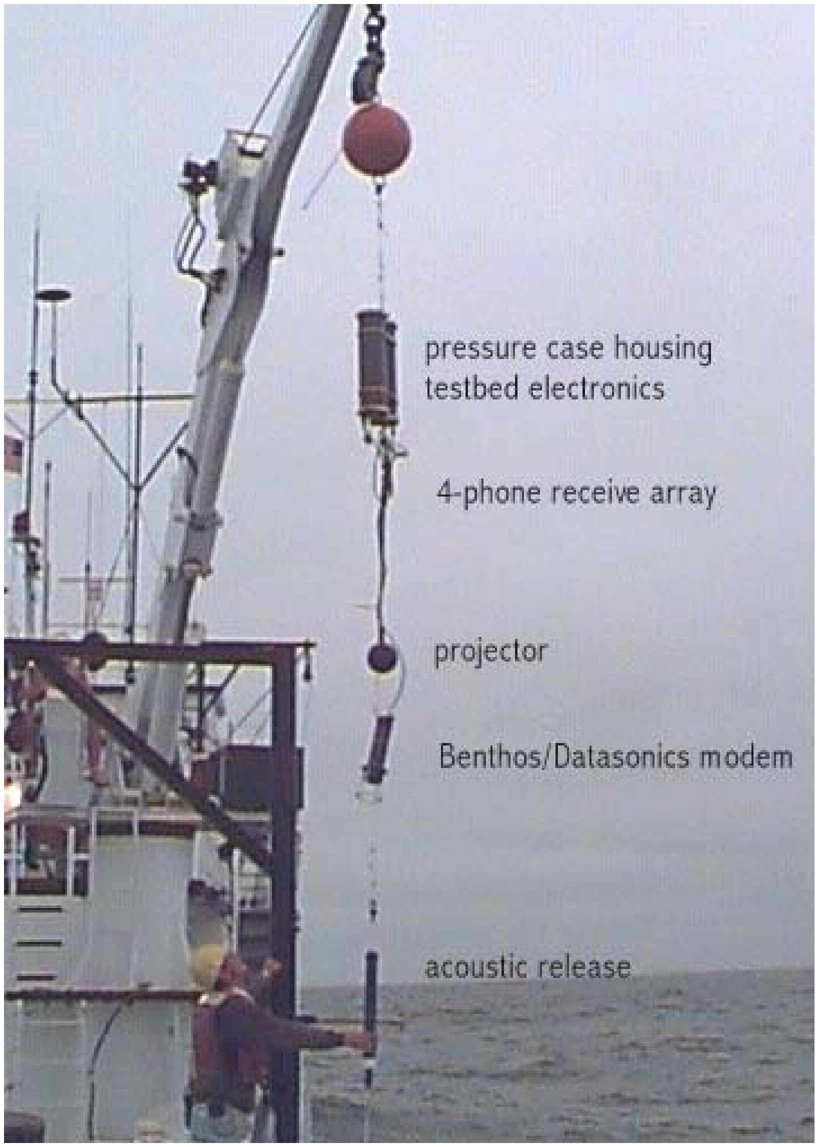

Fig. 1: Testbed configuration.

The key to this testing program is the versatile Telesonar Testbeds (Fig. 1), which have fully programmable mission-control software allowing us to transmit and receive all waveforms in any sequence. The hardware itself is now well tested and has performed flawlessly in recent tests.

WORK COMPLETED

SignalEx-B, -C, and -D were conducted in FY00 (April, May, and August 2000) in several different sites in the coastal U.S. as shown in Fig. 2. This year's work has focused on the data analysis as well as planning for FY02 testing. These first experiments have served to test the operation of both the hardware (the testbeds) and the internally fielded modem schemes.

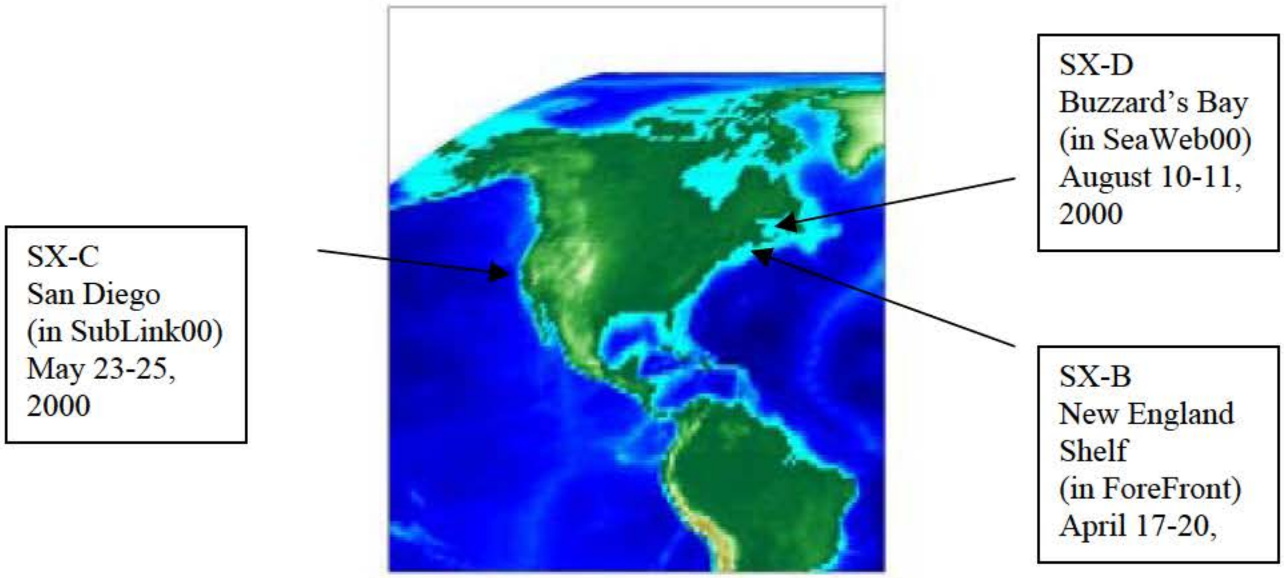

Fig. 2: Locations of the SignalEx tests.

In terms of the basic propagation physics, probes have been processed from both experiments (using M-sequences, LFM's, and combs) yielding a clear picture of the multipath structure. This in turn has been accurately modeled and interpreted using a Gaussian-beam channel-simulator[1,5] (BELLHOP) being developed with Paul Baxley. Finally, a website (http://sunspot.spawar.navy.mil/seaweb/signalex.htm) was established with complete information on the sea tests and results of the data analysis.

RESULTS

The new telesonar testbeds were tested first in an experiment over the New England Shelf during April 2000 (Fig. 3). The testbed was deployed on the ocean bottom in about 30 m of water and recorded waveforms transmitted from the R/V Connecticut as it drifted west, southwest of the testbed. The source was an over-the-side projector located at a depth of about 20 m.

Probe signals were sent every 5 minutes to measure both the Doppler shift/spread and the multipath spread. The impulse response was estimated using a sequence of LFM chirps in the 8-16 kHz band—the same band used by the communication waveforms. After doing the usual matched-filter technique one obtains the replica correlogram, which is shown in Fig. 4. The impulse-responses were then aligned by a leading edge.

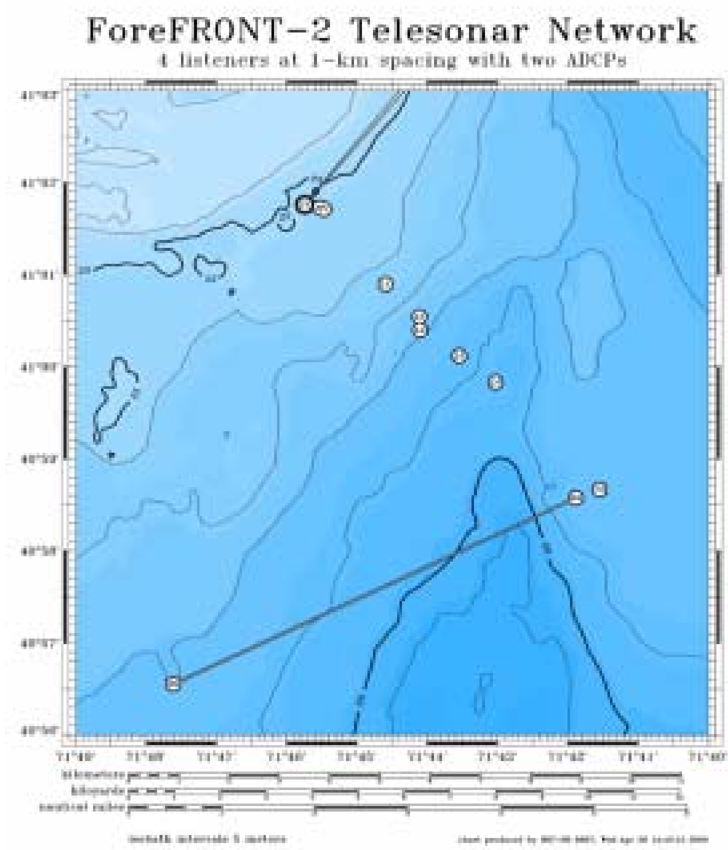

Fig. 3: Bathymetry and drift track during SignalEx-B.

As there are few published examples of these measurements of the impulse response for communications frequencies, there are several properties of interest. During the first hour of the experiment, the multipath spread increases. A simplified explanation of this is that the bottom may be treated as a homogeneous half-space leading to a critical angle; this causes strong absorption for ray paths with angles steeper than that critical angle. Thus the rays can only propagate within a fan up to the critical angle. With this angle fixed, the number of eigenrays that can reach a receiver increases as range increases.

Interestingly, after the first hour where range increases beyond about 1 km, the multipath spread starts to decrease again. Here the mechanism is that the loss per bounce becomes a strong effect (this is an exponential loss compared to the 1/r law of cylindrical spreading). This overall behavior of the impulse response is important for the design of most modem schemes since the multipath spread drives tone duration and/or clearing times for FSK schemes and the length of the tap-delay line used for schemes that use channel equalization. As a result, long-range communications may often be easier than short-range communications. Also of note is the reverberation, which causes fill-in between the multi-paths. However, the overall clarity of the 'echoes' is noteworthy.

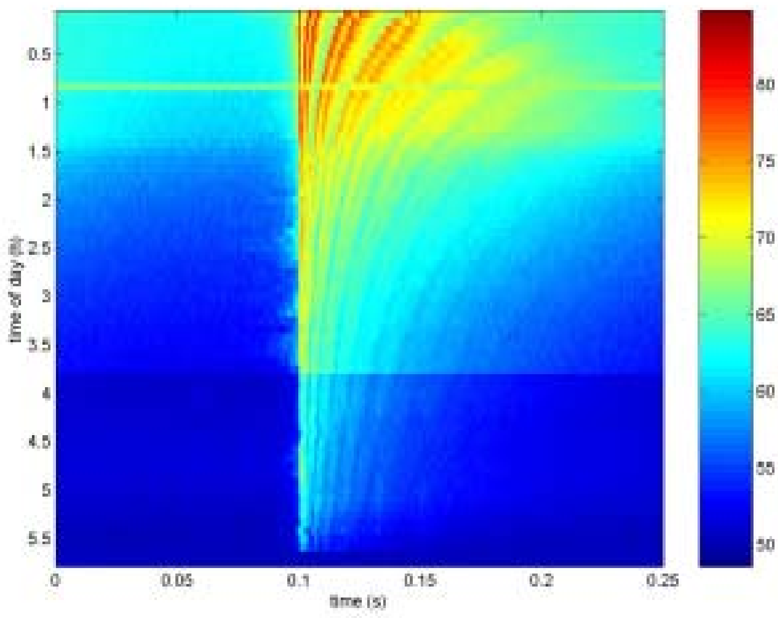

Fig. 4: Measured channel impulse response during the 6-hour drift.

A large number of modem schemes were tested during these two SignalEx tests. Here we focus on two schemes in particular, that are distinguished by being specifically designed to provide a multi-access capability. The two signaling schemes are FH-FSK (frequency-hopped, frequency-shift keyed) and DPSK (differential phase-shift keyed) scheme. A comparison of the bit-error rates for the two signaling schemes is shown in Table. 2. A waveform for each scheme was transmitted once every 30 minutes yielding a total of 11 datasets during the 5.5 hours of the experiment.

Both methods performed well during the test. It is important to emphasize that the error rates are presented as channel errors, i.e. before the error correction that results from the channel coding: This allows us to separate the channel coding from the fundamental physics affecting modem performance. After implementing the channel coding the FH-FSK scheme showed *zero* errors and a similar improvement is anticipated in the DPSK scheme.

The two methods had quite different error statistics. Often the DPSK method had exactly zero errors; however, on some of the datasets the error rate goes up significantly. We may say that the FH-FSK was more predictable. The reason for this is still being explored but it may reflect a shortcoming of the DPSK acquisition process rather than the data decoding itself. In stark contrast to other tests, neither of the methods shows sensitivity to the strongly changing propagation conditions (and in particular to the multipath duration).

IMPACT/APPLICATIONS

Just as cellular phones have greatly enhanced our personal freedom, wireless underwater systems provide tremendous flexibility in connecting to underwater systems, including ocean measurement systems such as CTD's and ADCP's; AUV's; and autonomous surveillance arrays. Wireless systems based on 802.11b and Bluetooth are currently emerging as the physical layer of the terrestial internet; similar systems based on acoustic technology will likewise form the backbone of the oceanic internet. Rapid and reliable signaling schemes will obviously be critical.

RELATED PROJECTS

This work is linked to the SeaWeb program at SPAWARSSC. Additional support was provided by ONR 321OA.

TABLE II
Bit-error rates (percent) for FH-FSK and DPSK schemes in SignalEx-B.

Dataset	*FH-FSK (30 bps)*	*DPSK (10 bps)*	*DPSK (50 bps)*	*DPSK (100 bps)*
1	*7.0*	*1.5*	*2.5*	*47.5*
2	*2.5*	*0*	*0.3*	*5.6*
3	*2.7*	*0*	*27.5*	*5.8*
4	*2.4*	*44.3*	*31.5*	*10.5*
5	*0.3*	*0*	*0*	*0*
6	*1.5*	*0*	*0*	*0*
7	*1.5*	*0*	*0*	*0*
8	*1.1*	*0*	*0*	*2.5*
9	*2.2*	*0.3*	*0.5*	*50*
10	*1.5*	*0*	*0.3*	*1.8*
11	*0.5*	*48.8*	*54*	*1*

PUBLICATIONS

[1] Michael B. Porter, Vincent K. McDonald, Paul Baxley, Joseph Rice, "Digital Underwater Acoustic Communications", Proceedings of the Australian Acoustical Society Meeting, pp. 123 Joondalup Resort, Western Australia, 15-17 November (2000).

[2] Paul Hursky, Michael B. Porter, Joseph A. Rice, Vicent K. McDonald, "Passive Phase-conjugate signaling using pulse-position modulation," *Proceedings of I.E.E.E. Oceans 2001*.

[3] M.B. Porter, V.M. McDonald, J. Rice, P. Baxley, "Channel characterization for high-frequency acoustic communications", (invited talk) *J. Acoust. Soc. Am.*, Vol. **109**(5):2449, Pt. 2 (2001).

[4] Paul Hursky, Michael B. Porter, Joseph A. Rice, Vincent K. McDonald, "Passive phase-conjugate signaling using pulse-position modulation", *J. Acoust. Soc. Am.*, Vol. **109**(5):2477, Pt. 2 (2001).

[5] Michael B. Porter, "Sound Propagation in the Ocean: A Mathematical Perspective", (Plenary Talk), *Program and Abstracts of the 2001 SIAM Annual Meeting*, July 9-13, San Diego, (2001).

[6] M.B. Porter, J.M. Tattersall, and J.P. Ianniello, "Assessment of 3D effects in the Key West experiment", *Journal of Computational Acoustics* ***9****:247-258* (2001).

[7] M.B. Porter and P.N. Mikhalevsky, "Ocean-Scale Acoustics", (invited talk), *Acoustical Oceanography*, Proceedings of the Institute of Acoustics, **23**(2):12-22, 9-12 April 2001, Southampton, UK (2001).