Underwater Acoustic Communications and Networks for the US Navy's Seaweb Program.

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ABSTRACT
At present, the realities of acoustic communications and undersea networks differ substantially from the expectations arising from academic theory and investigation. The issue is not that the fundamentals of communications theory do not apply, but rather the fact that the difficulties of the acoustic channel do not necessarily fit the assumptions underlying conventional applications of that theory. In this paper we describe many of the practical problems that have been addressed over the past ten years of modem development. Some of the issues addressed have an RF analog, but the severity of the channel and the combination of channel constraints and modem-platform operations makes acoustic communications a very different problem. In particular, we address these issues via their impact on physically small, battery powered, DSP-based, omni-directional modems. Next we describe progress toward using commercial acoustic modems as the basis for underwater networks. We discuss design choices at the physical, link, and network layers that are consistent with the compound constraints of the transmission channel and modem.

1. INTRODUCTION
The telesonar (i.e., telecommunications sound navigation ranging) acoustic modems shown in Figure 1 have a history dating back over ten years through initial efforts from Datasonics, subsequent funding from the Space and Naval Warfare Systems Command (SPAWAR), Office of Naval Research (ONR), Navy laboratories, and commercial activities. In the interim, Datasonics was purchased by Benthos, and now Benthos has been purchased by Teledyne. Modem capabilities have grown from a few tens of bits per second (bps) with marginal reliability to today's wide range of modulation schemes suitable for a wide range of environmental and operational conditions. At the same time, the size and power consumption of the modem has declined dramatically.

The original purpose of the telesonar modem was to be the platform for the development of undersea networking via the Seaweb program. This was the focus of the first funded efforts from SPAWAR, and this continues to be a major focus today. At the same time, ONR and other Navy laboratories have supported programs directed at the development of modem-based navigation aids, autonomous offboard sensors, and portable modem-based tracking ranges.

This paper first discusses in a general sense the impediments to acoustic communications (acomms). We then describe the characteristics of the telesonar modems. This description covers modulation techniques and a discussion of the most difficult part of acomms – the detection of the signal and the temporal and spectral alignment required for effective communications. Next comes an overview of Seaweb, the US Navy's undersea networking program, and, finally, we describe some experimental implementations of Seaweb.

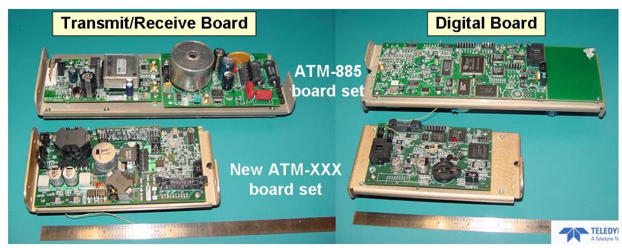

Figure 1. The current telesonar modem (lower board set) is the 4th-generation device developed in support of underwater networks and other applications. [1]

2. ACOUSTIC COMMUNICATIONS
The primary function of modems is to both transmit and receive signals that represent digital data—binary ones and zeros—over what usually is a hard-wired link such as a telephone line or a microwave link. In fact, the word modem is derived from the terms modulation and demodulation, which refer to the coding and transmission, and the receiving and decoding of digital data, respectively. Two key factors measure a modem's performance: speed and reliability. Speed is measured by determining the number of information bits transmitted per second, which is referred to as the bit rate. Reliability is measured by determining the bit error rate, which is the ratio of the number of bits received in error to the total number of bits transmitted.

[1] As with predecessor devices, such as the 3rd-generation modem, the engineering development was largely finanaced by US Navy Small Business Innovative Research (SBIR) grants, and the hardware is available as a commercial product.

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Except when noise interference is high, modems that transmit and receive data over phone lines or microwave links typically function nearly error free, and at baud rates of 128,000 bps or more. In addition, repeater systems allow virtually unlimited transmission ranges. Those same performance factors are also used to measure the capabilities of the undersea modems. However, with the transmission medium being water and the transmitted signals being sound, a number of physical barriers exist that constrain those performance factors, physical barriers that are not present in either wire or microwave links.

The major factors that constrain the performance of any communications system that uses water as a communications medium are the relatively slow speed of sound in water, the signal fading characteristics due to sound absorption and destructive interference, the multipath interference due to sea surface and sea floor reflections, and reflections from nearby objects.

The speed of sound in seawater, on average, is about 1500 meters/sec. This is compared to electromagnetic signals that travel at nearly the speed of light. However, the relatively slow speed of sound in seawater has no direct effect on the baud rate of the modems; it affects only the latency between the transmission of a signal and its reception. In most applications, this delay is not of much concern, as the alternative is to use a hard wired connection, which is sometimes prohibitively expensive or not feasible.

Signal fading is primarily caused by spreading loss and the absorption of sound in water, but it is also caused by destructive interference due to multipath, a situation where signals of like frequency nearly cancel each other. This frequency-dependent fading occurs when a multipath-induced reflection of the transmitted signal arrives at the receiving transducer at the same time as a transmitted signal of the same frequency. The result is a reduction in the amplitude of both signals. Signal fading due to spreading loss is a result of the dispersion of energy as it radiates outwardly from the transmitting transducer. And signal fading due to the absorption of sound in water increases with increasing frequency. To a lesser extent, environmental factors such as temperature, pressure, and salinity also affect absorption, and absorption also occurs at the sea floor.

Multipath is the factor that most restricts both the bit rate and the reliability of an acoustic modem. Multipath, which is particularly severe when attempting to communicate over the horizontal channel in shallow water, is the result of sea-surface and sea-floor reflections, reflections from objects that are near the receiving modem, and refractions from thermal gradients and water turbulence. Using directional remote transducers reduces the effects of multipath when the transducers are aimed at each other, yet reflections from objects such as piers or boats that are near the receiving transducer cause overlapping of the received signals, resulting in decreased reliability. In addition, multipath is usually not stationary; hence even techniques used to track and reduce the effects of multipath do not significantly improve modem performance in increasingly dynamic multipath situations. As a result, multipath forces continual trade-offs in the speed, the reliability, and the cost of acoustic modems.

3. TELESONAR MODEM

In addition to US Navy programs, these modems are in world-wide use by government agencies, industry, and academia. These applications represent more than ten years of experience in virtually every conceivable underwater channel. Although there is a strong theoretical underpinning to the modems, much of what "makes them work" is a compilation of enhancements reflecting lessons-learned in these many channels.

Probably the two most demanding requirements that have been placed on the telesonar modem come from, first, the National Oceanographic and Atmospheric Administration (NOAA), and second, from the Navy's premier developer and user of undersea tracking ranges. Both of these requirements are satisfied with data rates equal to or below 1200 bps.

The NOAA requirement was to provide a modem that could support the development of the national tsunami warning system. This application does not require the transmission of large volumes of data nor does it require high data rates. It does, however, demand very long life with few batteries, and an absolutely guaranteed transfer of sensor data into the modem, ready for transmission. These two requirements resulted in the development of a very low power "sleep mode," but one in which the modem would awaken immediately to either of two conditions: a) the arrival of an acoustic message, or b) the arrival of data over the RS232 port. In neither case can data be lost. Meeting this requirement resulted in a modem that sleeps at only 9 mW, whereas the normal fully awake (receive) mode consumes approximately 0.3 W.

The second requirement stems from the Navy's need to communicate with rapidly moving undersea platforms (high range rate). The conventional approach is to build a multi-hypothesis detector – essentially a bank of parallel matched filters, each tuned to a possible compression or dilation of a selected portion of the waveform. This is effective, well understood, and terribly demanding of computational resources. The solution to the requirement was the development of a patented algorithm, as described below. As an example of performance, the modem can effectively communicate with a ±30 kt platform operating with a modem designed for a standard 9-14 kHz band. This has been demonstrated by the US Navy to be fully effective with platforms moving in excess of 20 kts.

Table 1 summarizes the general capabilities of the 4th-generation telesonar modem which is the modem addressed in the remainder of this paper.

Table 1. Telesonar Modem Characteristics

Size	2 Boards 5.7" x 2.5" x 2.8"
Max Freq	70 kHz
Bandwidth	5-20 Khz
Power-Low	9 mw
Power-Active	300 mw
Input Voltage	10-60 vdc
Digital I/O	4 inputs, 5 outputs
Processing	200 MIPS
Memory-Ram	2 Mword
Non-coherent data rate	80-1200 bps
Coherent data rate	2500-10 000 bps

3.1 Modulation

We next describe the modulation techniques used in the telesonar modem. Three quite distinct modulations schemes each support different applications and provide different capabilities. All such schemes provide a transition to placing energy into the channel

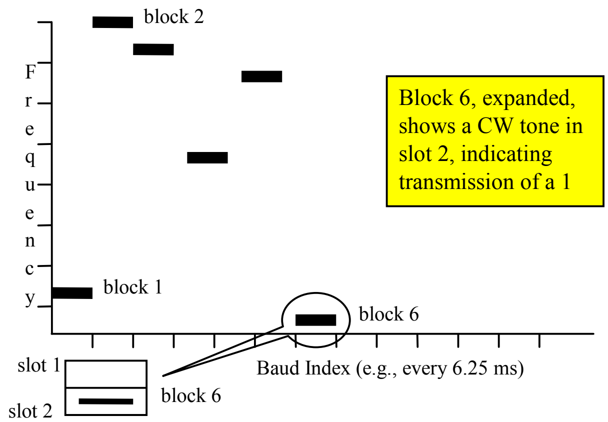

Figure 2. Example of Frequency-Hopped Binary FSK.

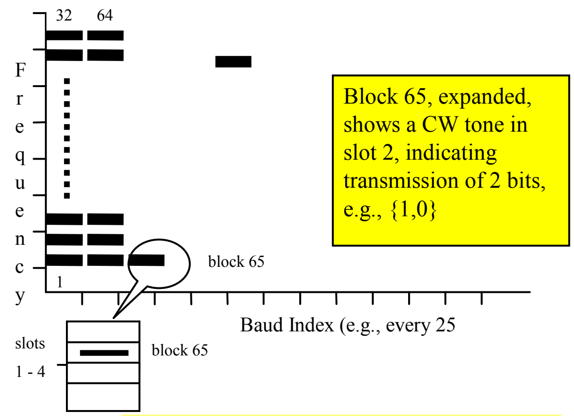

Figure 3. Example M=4 MFSK scheme transmitting 2 symbols with each tone.

同一个时间内，如何表示多个频率的信号

from a common path of data preparation. That path includes forward error correction coding (ECC) and symbol interleaving. The modulations all support standard base-2 Galois field arithmetic, with alphabet sizes of M = {2,4,8, etc.} [1]. We provide a brief overview of each modulation scheme in the following sections. For a more general overview of acomms, see [2].

3.1.1 Frequency Hopping

Frequency Hopping (FH) involves the placement of short continuous wave (CW) tonals at specific locations in frequency as time passes. Generally, we consider the placement of only one tone at one time, although this is not a fundamental requirement. Each tone conveys approximately ½ bit of information, with M = 2. Tones are orthogonally-spaced in frequency, and the scheme provides for approximately 80 bps of (true) data rate. Our scheme uses a pseudo-random frequency placement for the tones, and we employ a number of similar tonals as a precursor for signal acquisition and alignment.

There are three primary advantages to this form of waveform: the scheme is very tolerant of exceedingly long multipath; it is very good for low Signal-to-Noise Ratio (SNR) applications; and it can be made tolerant of the simultaneous presence of similar waveforms from multiple sources. That is, this can be considered a Code Division Multiple Access (CDMA) technique. There are also three drawbacks: the scheme is only tolerant of range rate (relative velocity) consistent with the inverse of the tonal duration; the range resolution is approximately limited by the tonal duration; and the data rate is quite low (80 bps in our case). Figure 2 shows a simple example in the time-frequency plane where M = 2 (binary).

3.1.2 Multi-Channel M-ary FSK

The term multi-channel M-ary FSK is not properly descriptive, but it has become the standard term used to describe the principal modulation method used in the telesonar modem. In this scheme we simultaneously transmit 32 tones spanning a 5120-Hz bandwidth. Two of the outer tones are used for Doppler tracking, while the remainder carry information. Each information tone may be placed in any of four adjacent frequency slots, which together form a block (there are thus 30 blocks). The selection of the slot is decided by the M=4 alphabet. At a data rate of 2400 bps, we transmit raw data without recourse to ECC or any other form of 'protection." At 1200 bps, we add ECC. For more reduced rates, we add various forms of redundancy and/or temporal separation of the tones. Available data rates range from 140 bps to 2400 bps. Figure 3 provides an example of this method.

Unlike the FH method, for this scheme we use several precursor waveforms for acquisition and alignment. In particular, this includes a patented method which permits these small, battery-powered devices to communicate with high-speed platforms. However, this method is ill-suited for multi-access applications.

3.1.3 M-ary PSK

This scheme supports communications at data rates from 2560 bps to approximately 15 kbps, although the latter is suitable only for ideal channels. Here we encode symbols via the use of extremely short tonals, all at the same frequency, with the phase of each tonal conveying the desired information. The success of this technique depends on the robustness of the Decision Feedback Equalizer (DFE) which resides at the receiver and which attempts to invert the propagation channel, as defined by its impulse response. In essence, the inversion process attempts to coherently combine all multipath into a single equivalent path. The performance of the DFE in turn is dependent on the statistical stationarity of the channel and the capability of the processor to handle the requisite number of feedforward and feedback equalizer taps (within the time defined by the tonal duration). The current implementation of the equalizer in the telesonar modem handles approximately 2-3 ms of multipath, and thus is best suited for vertical channels.

3.2 Signal acquisition and alignment

Acomms typically operates on the assumption that the arrival time of the signal is a completely unpredictable event. Therefore, it is necessary to incorporate a mechanism that can detect the arrival. It is also necessary to ascertain the precise start of the modulated message and to estimate the influences of channel spreading and platform range rate. It may also be desirable to estimate the spreading characteristics of the channel, as well as the SNR for the received signal. In the telesonar modem these are done nearly simultaneously.

With any wireless communications system provisions must be made to accommodate rapid relative velocity among users of the system. This is especially true of underwater communications, which have limited bandwidth and otherwise difficult channels.

All communications signals contain components used for acquisition and alignment, where, in the broadest sense, alignment pertains to both the temporal and spectral identification of the modulated portion of the larger signal. A typical signal component is a linear period modulated (LFM) waveform. This is processed with a "matched filter" using as a filter an exact replica of the transmitted LFM. The peak of the filtered output indicates the arrival time of the signal. When relative velocity (i.e., range rate) occurs, the waveform is distorted by temporal compression or dilation, which has the affect of also compressing/dilating the spectral content of the waveform. In this case the basic filter is no longer a good "match" for the received signal. The distortion causes a decrease in the peak filtered response, as well as loss of precision in estimation of temporal alignment. Furthermore, nothing is revealed about the spectral distortion of the signal. The desire here is to substitute an acquisition/synchronization subsystem which can provide acquisition of a packet and provide satisfactory alignment with the modulated message over a wide span of range rates. At the same time the acquisition must provide initial estimation of the range rate so the remainder of the signal can be corrected to enable the demodulation to proceed as if there were no motion present.

The classic method for solving this problem is to form a multi-hypothesis, maximum likelihood estimator, wherein a "bank" of filters are formed, each reflecting a different hypothesis of range rate. The number of filters used must account for the degree of spectral distortion imposed by the motion. Typically, a new filter must be used when the adjacent filter peak is reduced by 50%. The system then observes all of the filtered outputs and chooses that one with the largest peak. This "best" choice of filter then determines the range rate, which observation can be used to correct the remainder of the signal for the imposed spectral distortion.

The approach just described is considered optimal under typical conditions of an additive white Gaussian noise channel. However, the computational burden is very high, and, as in our case, may be prohibitive for a small, battery-powered digital signal processor (DSP). We describe next an alternative acquisition signal, which is robust in the presence of range rate, and which is combined with a secondary signal to identify the range rate. The combination of the two is used for purposes of both temporal and spectral alignment.

We have chosen to use a hyperbolic frequency modulated (HFM) signal for initial acquisition. Such signals have long been employed as sonar signals in anti-submarine warfare (ASW) situations. In this application, their ability to provide adequate detection performance in the presence of substantial range rate with the target submarine is well known. However, the peak arising from the matched filter process on the HFM experiences an (unknown) temporal offset which is a function of the range rate. This may or may not be of importance in ASW, but the misalignment is a serious problem in the communications context. We therefore follow the HFM waveform with a number of single-frequency tonals, all transmitted simultaneously. The number of tonals may be greater than or equal to one. Tonal signals are uniquely suited to producing a so-called doppler-shift, or spectral shift, which is a function of the range rate and the tonal frequency. Given the approximant alignment provided by the filtering of the HFM, we obtain a substantial portion of the tonals, and compute a power spectrum. The power spectrum is optimally based on a Fourier transform, although other transforms may be used. The tonals will produce peaks in the power spectrum. If these peaks are large enough, their spectral location is estimated and compared with the known transmitted frequency. The difference is a measure of the range rate. We average the range rates estimated from each of the tonals to obtain one estimate.

The range rate estimation from the tonals is used for two purposes. First, we correct for the alignment error imposed by range rate on the filtered HFM. Second, the compression/dilation of the modulated waveform is identified and is compensated for by conventional resampling methods which return the modulated signal to the form it would have had in the absence of range rate. We note that, in most of our non-coherent modulation schemes, we provide band-edge tracking tones which permit real-time, continuous correction for residual range rate.

3.3 Channel impulse response estimation

The output of the broadband matched filter may be interpreted as a band-limited estimate of the channel impulse response (IR). For example, Figure 4 shows two plots. The upper is a true "impulse response" which is convolved with a chirp waveform, as a representation of the linear nature of a channel. A matched filter (i.e., replica correlator) is applied to the resulting received signal, with the results shown in the lower plot. It is apparent that the lower is a reasonable, but not precise reflection of the upper plot. One may also employ a zero-forcing filter for this estimation, but, for our purposes, that is an unnecessary additional computation. We estimate the duration of the IR by first estimating the start of the IR (it may not be at the strongest peak), then computing the

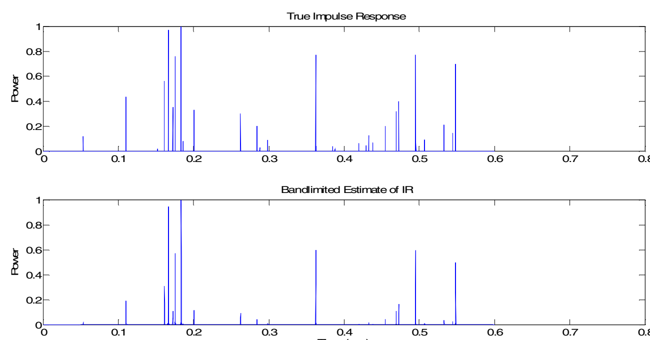

Figure 4. Examples of "true" impulse respone (top plot), and bandlimited estimation thereof (bottom plot).

point at which 95% of the energy is observed to represent the duration.

3.4 SNR estimation

One may estimate the output *SNRo* for a matched filter squared output *Z* from

$$SNRo = ((Pz - Mz)/\sigma z),$$

where Pz is the peak signal plus noise output, Mz is the mean of the noise (only), and σz is the standard deviation of the noise (only) output. The input *SNRi* may then be estimated via the simple relationship

$$SNRo = SNRi*(TWs)$$

where T is the duration of the signal (chirp) and Ws is the bandwidth spanned by the signal. This estimate is valid for additive Gaussian white noise in the absence of multipath, but it is a reasonably good indicator of "true" SNR under many real-world conditions.

4. SEAWEB

US Navy undersea wireless network development is following a concept of operations called Seaweb. Through-water telesonar modems using digital communications theory and digital signal processor (DSP) electronics is the basis for these underwater networks [3,4]. As depicted in Figure 5, Seaweb is tailored for battery-limited, expendable network nodes composing wide-area (order 100-10,000 km^2) oceanographic sensor grids for long-term synoptic observation [5,6] in situations where cabled or buoyed sensor arrays would be vulnerable to trawling, pilfering, and ship traffic. Seaweb networking provides acoustic ranging, localization, and navigation functionality [7], and thereby supports the participation of mobile nodes, including submarines [8] and collaborative swarms of autonomous undersea vehicles (AUVs) [9]. Seaweb networking can include clusters of nodes forming a high-bandwidth wireless acoustic local-area network (aka Seastar) that operates at higher frequencies and shorter ranges than the Seaweb wide-area network. The Seaweb blueprint accommodates the incremental introduction of directional, channel-adaptive, situation-adaptive, self-configuring, self-healing mechanisms required for unattended operations in littoral waters. Seaweb networking includes a repertoire of communication gateways serving as interfaces between the distributed undersea sensor nodes and manned command centers ashore, afloat, submerged, aloft, and afar. Telesonar modems form the wireless undersea links. Gateways to manned control centers include adaptations to submarine sonar systems (Sublink) and radio/acoustic communication (Racom) buoys with links to sky or shore.

Seaweb development demands attention to the underlying critical issues of adverse transmission channel, asynchronous networking, battery-energy efficiency, information throughput, and cost. Seaweb development follows a spiral development process involving applied research, incremental prototypes, and periodic testing at sea [10]. The Seaweb network provides the physical, link, and network layers as represented in the International Standards Organization's Open Systems Interconnection (ISO/OSI) model.

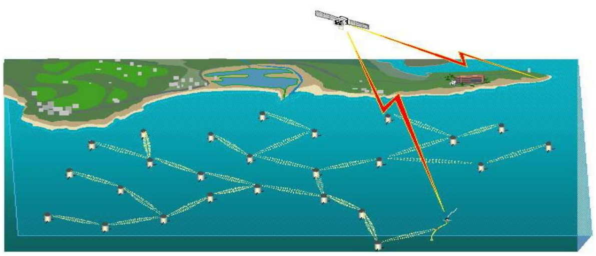

Figure 5. Seaweb through-water acoustic networking enables data telemetry and remote command & control for undersea sensor grids, autonomous instruments, and vehicles.

At the physical layer, an understanding of the transmission channel is gained through propagation theory and ocean testing. Tools include numerical physics-based channel models [11], channel simulations [12], and portable telesonar testbeds [13] for controlled sea measurements with high-fidelity signal transmission, reception, and data acquisition. Knowledge of the fundamental constraints on telesonar signaling translates into increasingly sophisticated digital communications techniques matched to the unique characteristics of the underwater channel. Variable amounts of forward-error correction allow for a balance between information throughput and bit-error rate. A raw symbol rate of 2400 bits/s is reduced to an effective information bit-rate based on the degree of coding, redundancy and channel tolerance desired. At present, 800 bits/s is the nominal information bit-rate, with provision for reduction to 300 bits/s if so required by the prevailing channel conditions. At present, the physical layer is based exclusively on MFSK modulation of acoustic energy in the 9-14 kHz band.

At the link layer, compact utility packets are well suited to meeting the constraints of slow propagation, half-duplex modems, limited bandwidth, and variable quality of service [14]. The telesonar handshaking process automatically addresses and ranges the hailed node. Reliability is enhanced through the implementation of negative acknowledgements, range-dependent timers, retries, and automatic repeat requests [15]. Important features of the Seaweb link layer are illustrated in Figures 6 and 7.

As described by Table 2, at the network layer, routing and navigation are accomplished through embedded data structures distributed throughout the network. Seaweb neighbor tables maintain information about adjacent nodes within a 1-hop range. Seaweb routing tables dictate the neighbor nodes having networked connectivity with the intended destination node. Neighbor-Sense Multiple Access (NSMA) is a network layer function that passively monitors Seaweb traffic as a means of ascertaining the communications status of neighbor nodes. NSMA provides a means for avoiding unnecessary collisions by politely waiting for Seaweb dialogs to conclude before initiating new dialogs. At the command center, a Seaweb server maintains the neighbor table and routing table data structures, supports network configurability, manages network traffic at the gateways, and provides the graphical user interface for client workstations [16]. Seaweb is an inherently long-latency communication system. Critical source-to-destination delivery can be confirmed through the use of return receipts implemented efficiently as Seaweb utility packets.

5. EXPERIMENTAL IMPLEMENTATIONS

Seaweb is implemented as Navy-restricted firmware operating on Benthos commercial modem hardware [17]. The power of Seaweb connectivity was successfully demonstrated during recent experiments depicted in Figures 8-11. Figure 8 shows a collection of gliders fitted with telesonar modems exercised as mobile nodes in an experiment conducted with DRDC of Canada. These gliders, manufactured by Webb Research of Falmouth, Massachusetts, contain. **GPS,** Iridium, FreeWave, and ARGOS in the tail section. Such communications assets, when combined with the onboard acoustic modem, make these AUVs effective mobile gateway nodes without the attendant vulnerability of moored gateways. Ad Hoc networks employing the AUSI Solar AUV (SAUV) with a similar collection of communications equipment are under development at the US Navy Undersea Warfare Center. Figure 9 shows both vehicles.

Two substantial exercises were conducted with the US Navy, as depicted in Figures 10 and 11. In the former, a submarine maneuvered around a 14-node Seaweb network accompanied by two RACOM buoys. This was the first example of email being sent over wireless acoustic links from the submerged submarine to an ashore command center. In the latter, an experiment in 2004 demonstrated the reliability of the Seaweb network as it repeatedly overcame disruption to the pre-planned network caused by two hurricanes and, more significantly, severe trawling. The figure on the left shows the planned deployment, while that on the right shows the reconstructed, and fully functional, network locations at the end of the experiment.

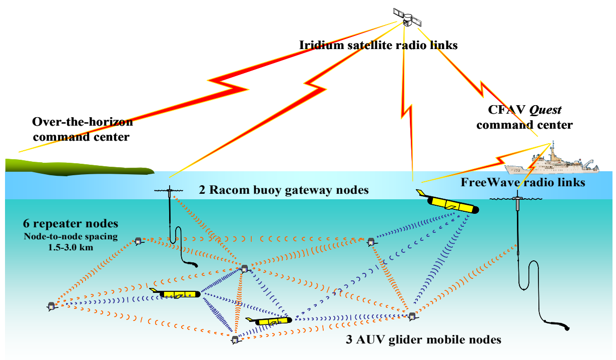

Figure 8. The February 2003 Q272 Seaweb network in the Eastern Gulf of Mexico included three AUVs, six repeater nodes, and two gateway buoys

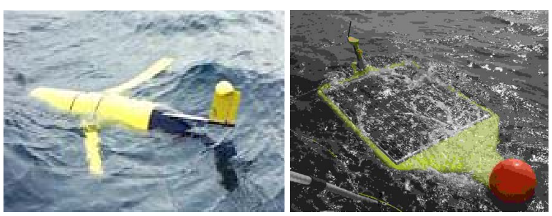

Figure 9. Left: SLOCUM gliders are buoyancy-driven mobile Seaweb nodes for which acoustic sensors and towed arrays are now being developed. Right: SAUV is a solar-powered propeller-driven AUV with a virtually unlimited life. SAUV is also fitted with telesonar, Iridium, FreeWave, and GPS.

6. CONCLUSION

Reliable underwater acoustic communications are now available for a very wide range of environmental conditions and operational situations. Evolutionary developments in undersea networks have paralled the development of Telesonar modem technology. Seaweb concepts originated with the OSI model, but have been modified to reflect practical experience gained over nearly ten years of at-sea experiments and demonstrations. Different end-use customers have driven technological advances, including very low power sleep and wakeup, and robust links under high range rate conditions. Different constraints on both basic acomms and networks apply depending on the supporting infrastructure: power sources, computational resources, and spatial diversity. For most autonomous subsea systems, the constraints can be severe, especially with regard to multipath, time-varying channel complication that has not been adequately addressed, in part because many of the limitations of fixed networks still have not been overcome.spreading, interference, range rate, power, volume, and weight. The development of *ad hoc* mobile networks is a further complication that has not been adequately addressed, in part because many of the limitations of fixed networks still have not been overcome.

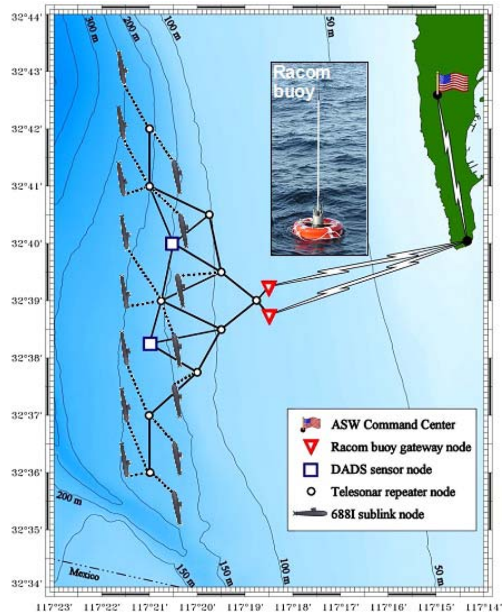

Figure 10. A June 2001 Seaweb network was a 14-node undersea grid installed on the Loma Shelf adjacent to San Diego (left). Mobile positions near the nodes are indicated by the submarine icon.

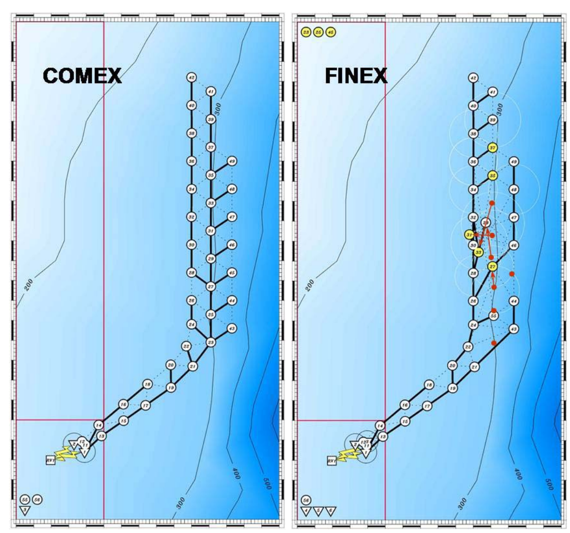

Figure 11. Experiment conducted in 2004 with 40 nodes. Figure on the left shows the planned deployment, while the right hand figure shows the final position following hurricanes and trawling.

7. ACKNOWLEDGMENTS

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Table 2. Seaweb Utility Packet Functionality
The utility packets are 9-byte messages containing several parameter fields, some of which are common to all packet types and others are specific to each type. The packet type dictates how the message is handled in the protocol.

Modem Addressing	Link-layer transmit and receive addresses are used to indicate the source and intended recipient of an acoustic packet. A receive address of 0 indicates the message is a broadcast packet and shall be handled by all recipients. The transmit and receive addresses - The fields are common to all types.
Network-Layer Addresses	The network-layer Source, Destination and Cell (last hop) addresses are used in specific utility packets that move data/commands through multiple hops in a network. These addresses indicate the final destination and the originating modem identifiers. The Cell address is used by a data originator to attempt communications to a destination address via a Cell address. This Cell address is useful when communicating with non-stationary destination nodes.
CRC Field	A forward error correction field using an 8 bit cyclic redundancy check field is used to for all packet types.
Link-layer Handshake	Preceding the transmission of data packets, a message handshake consisting of a Request-To-Send (RTS) and Clear-To-Send (CTS) is utilized. This handshake allows the transmitting modem to prepare the recipient modem to receive a message. The RTS message indicates the size of the pending packet, the number of RTS attempts that will be tried, the number of Selective Repeat Requests (SRQs) that should be attempted, and the Receipt Request indicator.
Size and Modulation Indicator for Data Types	The Data Header utility type indicates the amount of data and modulation used transmitting the data packet. Both the packet size and modulation are 16 bit fields to allow for a wide range of packet sizes and modulation options.
Selective Repeat Request (SRQ)	A method of automatic repeat request (ARQ) is used called SRQ. This SRQ allows a receiving modem to request that a corrupted part of a received data packet to be retransmitted. This is useful when a small portion of a received data packet becomes corrupted. Instead of discarding what was received without errors, the receiving modem keeps those parts and only requests the affected segments of the data to be retransmitted.
Receipt Requests	The Receipt Request allows a modem sending data to request an acknowledgement of receipt from the destination modem. Two packets types, the RTS and Data Header, contain the Receipt Request flag which indicates to the destination modem that upon receiving a message a "Receipt" type packet shall be transmitted back to the source of the message. Furthermore, if a packet cannot be transmitted to the destination modem due to link failures, then the last modem holding the packet before the failure shall send a Receipt packet indicating failure to deliver the packet to its destination.
Node Ranging	A means of obtaining a 2-way range calculation between modems is available via the Ping and Echo message types. The Ping type contains a destination address thus indicating to the receiving modems which node is the intended recipient. The recipient of the Ping packet responds with an Echo packet after a constant response time. Once the Echo packet is received, a range in tenths of meters is calculated between nodes.
Broadcast Ranging	A special case of node ranging is the broadcast range. In this case, the broadcast address is used and all recipients of the broadcast Ping message shall respond with Echo packet type. A random time interval is selected by each recipient for transmission of the Echo response. The usage of time intervals on the response is the method used to prevent all nodes from transmitting at once and thereby acoustically corrupting the Echo response.
Brevity Packets	A special packet type noted the Brevity packet transmits packets with up to 64 bytes of data without using RTS-CTS handshake before the data. This packet type is acknowledged via a positive acknowledgement protocol. This positive acknowledgement is transmitted for every successfully received packet.
Sequence Numbers	8-bit sequence numbers are used in the RTS, Data, and Brevity packets to yield a chronological sequence to data transmissions. The modem originating the data creates a sequence number and increments that number for each new packet carrying application data.
Neighbor Sensing	A concept called "Neighbor Sense Multiple Access" is used by the modems when enabled to track the state of communications among neighbors. This allows a modem to hold off from sending data to a neighbor that is currently exchanging messages to other modems.