Seaweb Acoustic Com/Nav Networks

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ABSTRACT

Seaweb networks interconnect fixed and mobile nodes distributed across a wide area in the undersea environment. Acoustic communications between neighboring DSP-equipped telesonar modems is the basis for the physical layer. Node-to-node ranging is a by-product of telesonar signaling, permitting localization of sensor nodes and navigation of mobile nodes such as submarines and autonomous vehicles. The unusual characteristics of the physical-layer medium constrain the design of the link and network layers. Seaweb data-packet communications are achieved through the ancillary use of compact channel-tolerant utility packets. Measuring the available acoustic channel permits link optimization by adapting the data-packet signal parameters to the prevailing channel attributes. Link-layer methods including forward error correction, handshaking, and automatic repeat request provide reliability. Network-layer mechanisms such as distributed routing tables, neighbor-sense multiple access, packet serialization, and return receipts enhance quality of service. This paper reviews the concept of operations for undersea networks with illustrative examples of actual Seaweb deployments.

INTRODUCTION

US Navy undersea wireless network development is following a concept of operations called Seaweb [1]. Through-water telesonar (i.e., *tele*communications *so*und *na*vigation *r*anging) using digital communications theory and digital signal processor (DSP) electronics is the basis for these underwater networks [2,3].

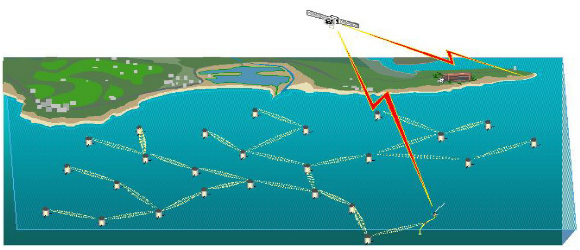

Figure 1. Seaweb through-water acoustic networking enables data telemetry and remote command & control for undersea sensor grids, autonomous instruments, and vehicles. Telesonar modems form the wireless undersea links. Gateways to manned control centers include adaptations to submarine sonar systems (Sublink) and radio/acoustic communication (Racom) buoys with links to sky or shore.

As depicted in Figure 1, 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 [4,5] 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 [6], and thereby supports the participation of mobile nodes, including submarines [7] and collaborative swarms of autonomous undersea vehicles (AUVs) [8]. 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.

TECHNICAL APPROACH

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 [9]. The Seaweb network provides the physical, link, and network layers as represented in the International Standards Organization's Open Systems Interconnection (ISO/OSI) model.

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 [10], channel simulations [11], and portable telesonar testbeds [12] 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 M-ary Frequency Shift Keying (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 [13]. 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 [14]. Important features of the Seaweb link layer are illustrated in Figures 2 and 3.

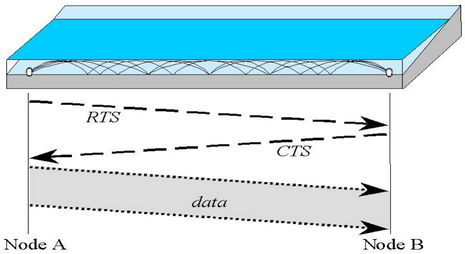

Figure 2. Seaweb link-layer handshake protocol for data transfer involves Node A initiating a request-to-send (RTS) utility packet. So addressed, Node B awakens and demodulates the RTS. Node B responds to A with a clear-to-send (CTS) utility packet that fully specifies the modulation parameters for the data transfer. This protocol anticipates the spiral development of adaptive modulation wherein Node B uses the RTS as a channel probe and estimates the channel scattering function. With this knowledge, Node B then specifies optimal signaling parameters for the data packet as part of the CTS handshake.

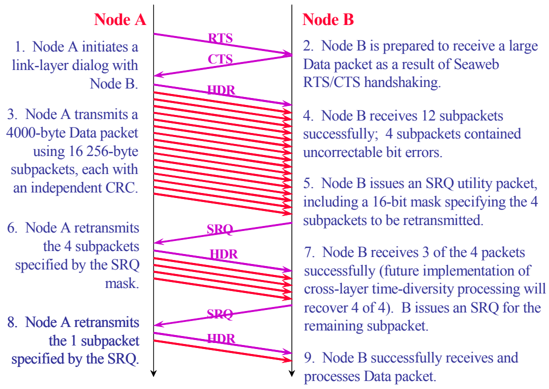

Figure 3. Selective ARQ (SRQ) is a link-layer mechanism for reliable transport of large data files between neighboring nodes even when the physical layer suffers bit errors uncorrectable by forward error correction, as depicted in the example here. Purple arrows are Seaweb utility packets. Red arrows are data sub-packets.

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 [15]. 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.

EXPERIMENTAL IMPLEMENTATIONS

Seaweb is implemented as Navy-restricted firmware operating on Benthos commercial modem hardware [16]. The power of Seaweb connectivity was successfully demonstrated during recent experiments described in Figures 4-7.

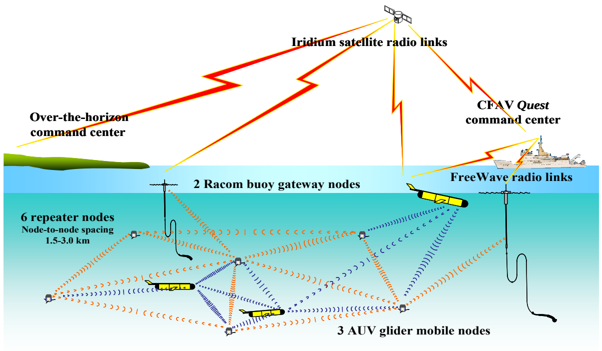

Figure 4. The February 2003 Q272 Seaweb network in the Eastern Gulf of Mexico included three AUVs, six repeater nodes, and two gateway buoys. The experiment exercised Seaweb ranging functions for tracking and navigating mobile nodes. The AUVs proved themselves as effective mobile gateway nodes with telesonar, FreeWave, Iridium, ARGOS, and GPS.

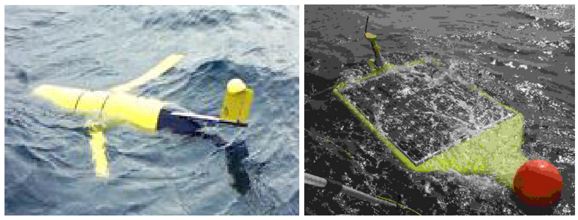

Figure 5. *Left*: SLOCUM gliders are buoyancy-driven mobile Seaweb nodes for which acoustic sensors and towed arrays are now being developed. Telesonar transducer in the nose section, combined with GPS, Iridium, FreeWave, and ARGOS in the tail make these AUVs effective mobile gateway nodes without the attendant vulnerability of moored gateways. *Right*: SAUV is a solar-powered propeller-driven AUV with a virtually unlimited life. SAUV is also fitted with telesonar, Iridium, FreeWave, and GPS.

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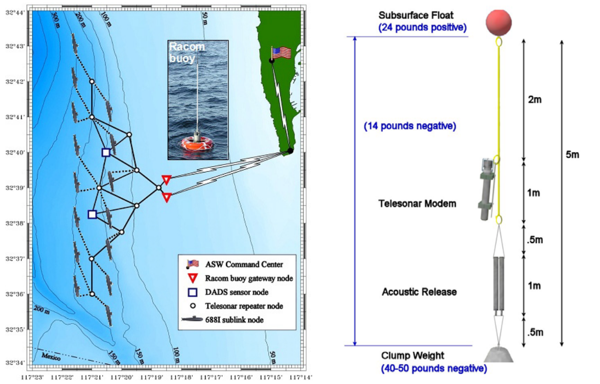

Figure 6. The June 2001 FBE-India Seaweb network was a 14-node undersea grid installed on the Loma Shelf adjacent to San Diego (left). Two nodes were ASW sensors, ten were recoverable telesonar repeaters (right) on the seafloor, and two were moored Racom buoys (inset). A submarine with Sublink capability had full interoperability with the Seaweb network. Seaweb servers aboard the submarine and at the ashore ASW command center provided a graphical user interface and a portal for the autonomous sensor operator display. Seaweb traffic originated asynchronously at the two sensor nodes, at the submarine, and at the ASW command center. The Seaweb link-layer protocols automatically resolved network contentions whenever Seaweb transmissions collided. Test personnel exercised the complete Seaweb installation for four days with high reliability and no component failures.

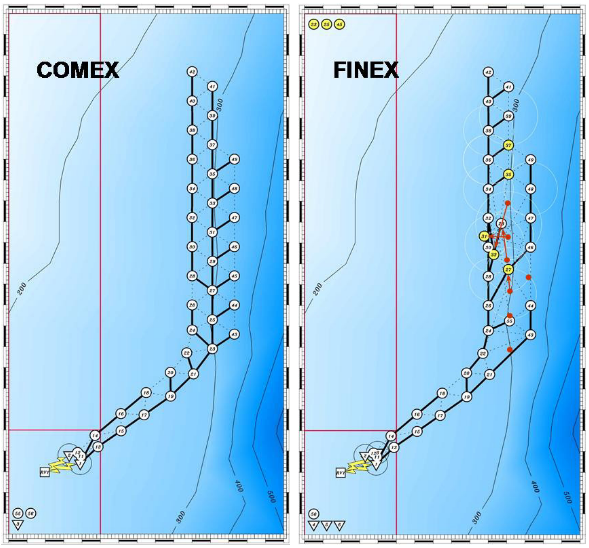

Figure 7. In a 2004 experiment on the outer continental shelf, a wide-area grid of 40 Seaweb repeater nodes (circles) deployed on the seafloor provided cellular access points for an undersea vehicle. Networked communications from the cellular grid was via Racom buoys (triangles) to the shipboard command center (square). The bold connections represent Seaweb network routing. The lightning bolts (yellow) represent FreeWave line-of-sight radio communications between the moored Racom buoys and the ship. Impact by trawling (red annotations) disrupted Seaweb service and compelled operators on the ship to heal the network by remotely reconfiguring network routes.

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