Undersea Networked Acoustic Communication and Navigation for Autonomous Mine-Countermeasure Systems

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Abstract— Telesonar underwater acoustic modem technology has attained a level of maturity sufficient to support undersea wireless communication networks, as dramatically demonstrated during Fleet Battle Experiment India (FBE-I) in June 2001. Telesonar network development is following a concept of operations called seaweb. The seaweb blueprint is tailored for battery-limited network nodes composing wide-area (order 100-10,000 km^2) sensor grids. Seaweb already enables the development of littoral surveillance systems such as the Deployable Autonomous Distributed System (DADS) and continental-shelf observatories such as the Front-Resolving Oceanographic Network with Telemetry (FRONT). Seaweb networking provides acoustic ranging, localization, and navigation functionality, and supports the participation of mobile nodes as members of the wide-area network. These mobile platforms include manned submarines and unmanned undersea vehicles (UUVs) that crawl, swim, glide, and drift. Seaweb supports expeditionary operations in contested waters, with communication gateways to manned command centers submerged, afloat, aloft, ashore, and afar. The seaweb wireless infrastructure naturally extends into mined areas, providing cross-platform, cross-mission interoperability with anti-submarine-warfare (ASW), intelligence-surveillance-reconnaissance (ISR), and meteorology-oceanography (METOC) systems. This paper introduces seaweb to the mine-countermeasures (MCM) community, and addresses the communication and navigation issues associated with autonomous sensors and UUVs. *This work sponsored by ONR 32 and the Navy SBIR Program.*

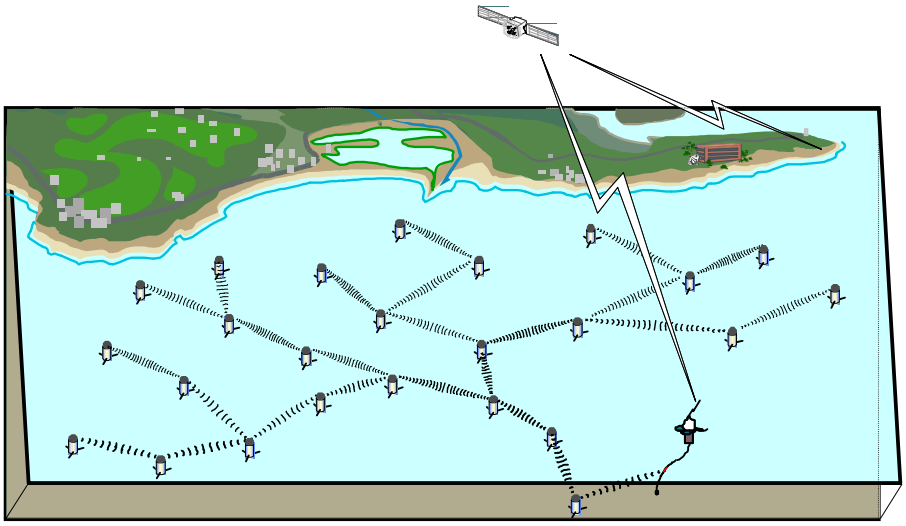


Figure 1. Seaweb underwater acoustic networking enables data telemetry and remote control for undersea sensor grids, vehicles, and other autonomous instruments. Gateways to manned control centers include radio-acoustic communications (racom) nodes with radio links to sky or shore.

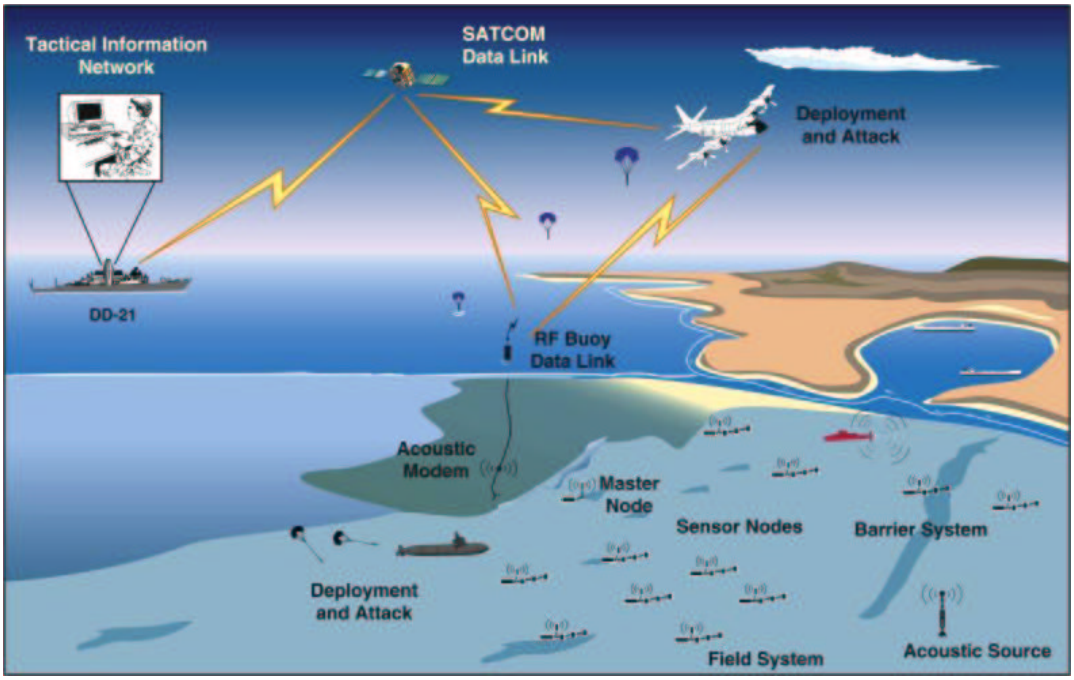
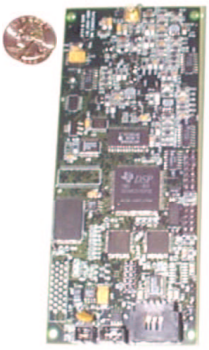


Figure 2. The Deployable Autonomous Distributed System (DADS) is a littoral anti-submarine warfare (ASW) future Naval capability in development by ONR, SPAWAR Systems Center, and Undersea Sensor Systems Inc (USSI). DADS involves acoustic, magnetic, and electric sensors, node-level sensor fusion, field-level data fusion, and communications via seaweb wide-area networks and racom gateway buoys. Application of seaweb networking to DADS anticipates the ultimate need for automatically bootstrapping sensor networks following rapid deployment in ad hoc configurations. This process includes discovering neighbor nodes, geo-localizing the sensors, optimizing the network topology, and maintaining the battery-powered network for the prescribed life of the system. *Graphic courtesy of Tom Roy, SPAWAR Systems Center, San Diego.*



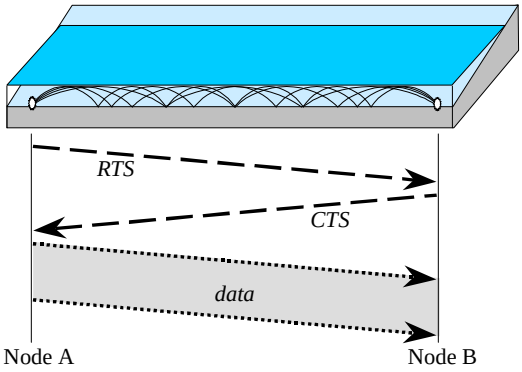


Figure 3 (left). The Benthos ATM885 telesonar modem with TMS320C5410 digital signal processor (DSP) offers a four-fold increase in memory and processing speed over the ATM875 telesonar modem, providing capability consistent with planned seaweb functional developments through 2006. Commercial telesonar modem hardware was developed as a Navy Small Business Innovative Research (SBIR) investment. A high-bit-rate modem now in development uses the ATM885 as a motherboard, thus ensuring interoperability. ***Photo courtesy of Ken Scussel, Benthos, Inc.***

Figure 4 (right). Telesonar handshake protocol for data transfer involves node A issuing a request-to-send (RTS) modulated with a channel-tolerant, spread-spectrum pattern uniquely associated with intended receiver node B. So addressed, node B awakens and demodulates the fixed-length RTS packet. Node B estimates the channel parameters using the RTS as a probe signal. Node B responds to A with a fixed-length clear-to-send (CTS) that fully specifies the modulation parameters for the data transfer. Node A then sends the data packet(s) with optimal source level, bit-rate, modulation, and coding. The process of probing and estimating the prevailing channel conditions, and then optimizing the data transmission, is known as "adaptive modulation." If node B receives corrupted data, it initiates a selective automatic repeat request (ARQ). An updated measurement of the range between the pair of communicating nodes is a by-product of the handshaking, and is the primary basis for node geo-localization and tracking algorithms. RTS, CTS and ARQ are among the 16 different utility packet formats used for communication and navigation functions.

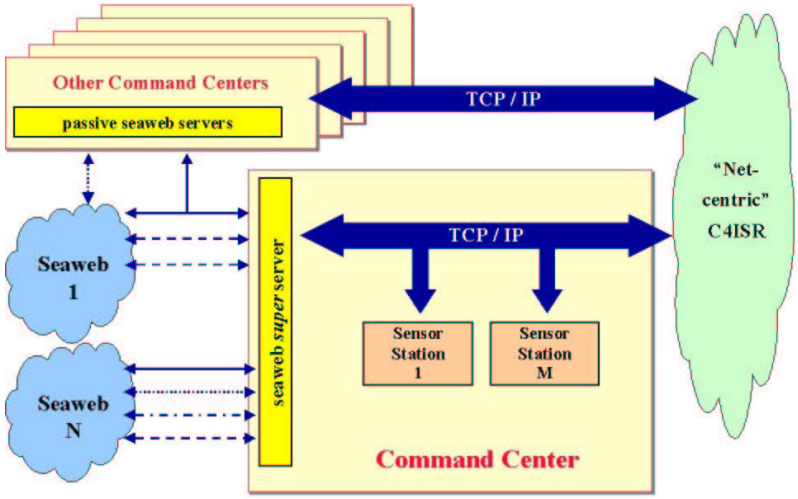
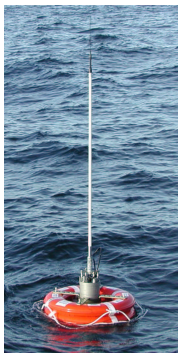


Figure 5. Seaweb extends modern "net-centric" interconnectivity to the undersea realm. Wireless underwater networks include gateway nodes with radio, acoustic, wire, or fiber links to manned command centers where a seaweb server provides a graphical user interface. At a designated command center a seaweb "super" server manages the undersea network. Seaweb servers archive information packets and provide data access to sensor stations via a database management system.



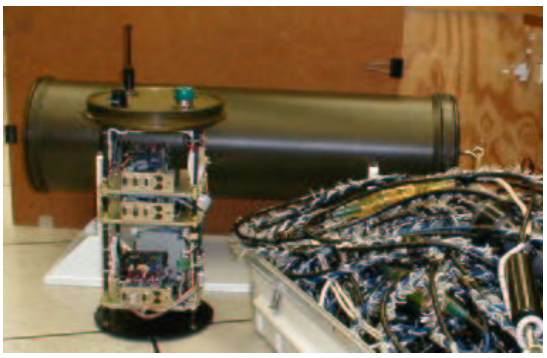


Figure 6 (left). A radio/acoustic communication (racom) buoy equipped with line-of-sight Freewave digital packet radio. ***Photo courtesy of Ken Rogers, SPAWAR Systems Center, San Diego.***

Figure 7 (right). An Experimental Development Model (XDM) of a DADS sensor node was developed by SPAWAR Systems Center, San Diego. It includes sensors, computers, batteries, and a Benthos ATM885 telesonar modem. The XDM sensor node has successfully performed against surrogate threat submarines during experiments at sea. ***Photo courtesy of Duane Sample, SPAWAR Systems Center, San Diego.***

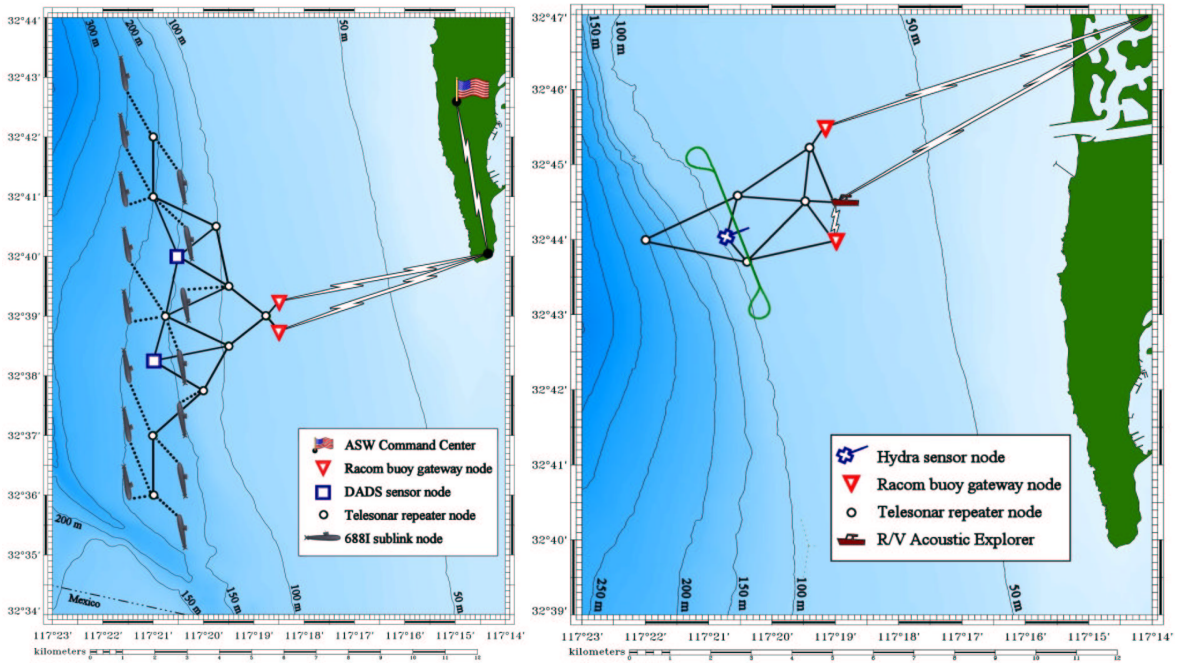
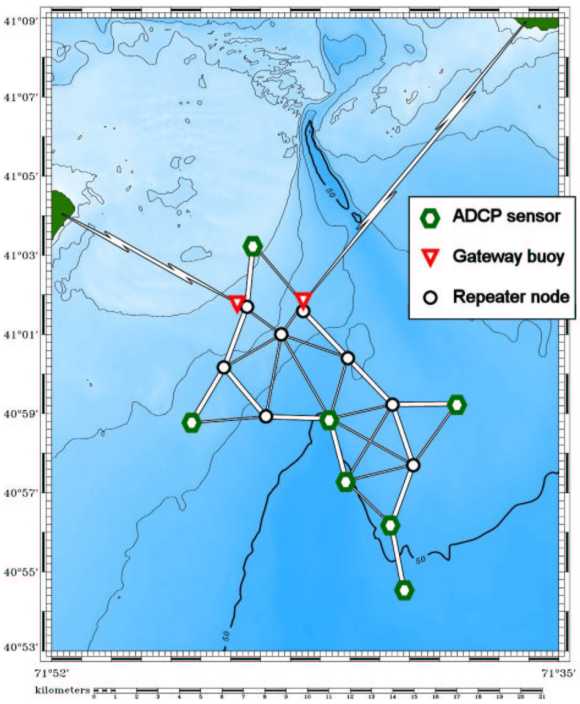


Figure 8 (left). The FBE-I seaweb network was a 14-node undersea grid. Two nodes were XDM DADS sensors, and two were moored racom buoys. An improved 688-class fast-attack submarine with sublink capability had full interoperability with the seaweb network. Seaweb servers aboard the submarine and at the ashore ASW command center provided a graphical user interface. Network traffic was asynchronously produced at the two DADS nodes, at the submarine, and at the ASW command center. Network contentions were autonomously handled by the seaweb media-access-control (MAC) protocols. Test personnel exercised the complete seaweb installation for four days with high reliability and no component failures.

Figure 9 (right). The Seaweb 2001 Experiment supported testing of a Hydra deployable autonomous undersea system operating in the presence of USS Dolphin acting as a surrogate ASW threat. Seaweb supported remote control of Hydra and telemetry of matched-field-tracking (MFT) results.



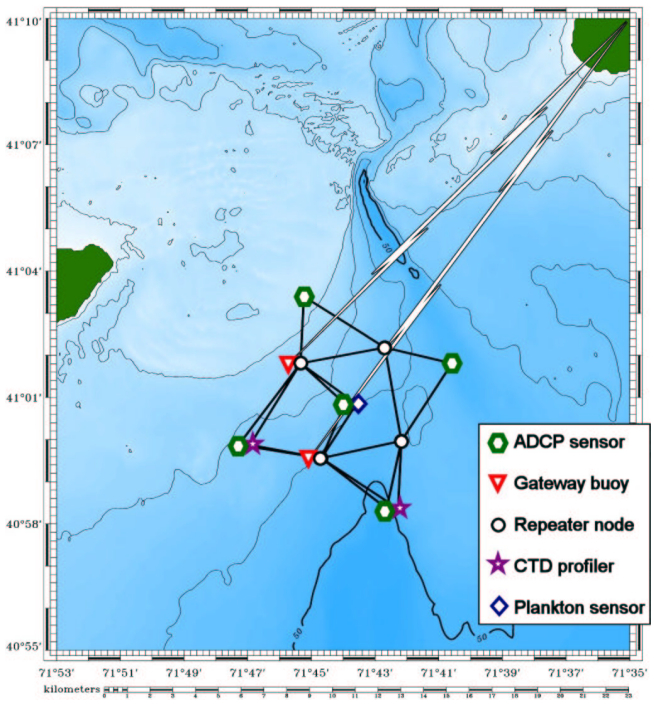


Figure 10 (left). The FRONT-3 seaweb network includes 2 sea-surface cellular digital packet data (CDPD) racom gateway nodes, 7 seafloor acoustic Doppler current profiler (ADCP) sensor nodes and 8 seafloor repeater nodes. The repeater nodes reduce node spacing and improve overall quality of service. 2 of the repeaters are adjacent the racom buoys to ensure reliable links between the seafloor grid and the sea-surface gateways. Binary-tree routing topologies as shown with bold white segments minimize multi-access channel contention for half-duplex telesonar links. Routes are configurable by the ashore network administrator using the seaweb server. Although statistics are not yet compiled for FRONT-3 network performance, the 17-day ForeFRONT-3 engineering network delivered 85% of the ADCP data packets to shore with 0 bit-errors.

Figure 11 (right). Plans for the FRONT-4 seaweb network call for 2 CDPD racom gateway nodes, 5 ADCP sensor nodes, 1 autonomous vertically profiling plankton observatory (AVPPO), 2 conductivity-temperature-depth (CTD) vertical profilers, and at least 4 repeater nodes. The FRONT-4 network will use Seaweb 2001 firmware and will operate for up to 6 months. ForeFRONT-4 will test a subset of the FRONT-4 network for risk mitigation.

Figure 12. Immediately preceding FRONT-3 deployment, project personnel programmed and exercised the seaweb network and the seaweb server as an in-air acoustic network for 2 weeks. *Photo courtesy of Dan Codiga, University of Connecticut, Avery Point.*

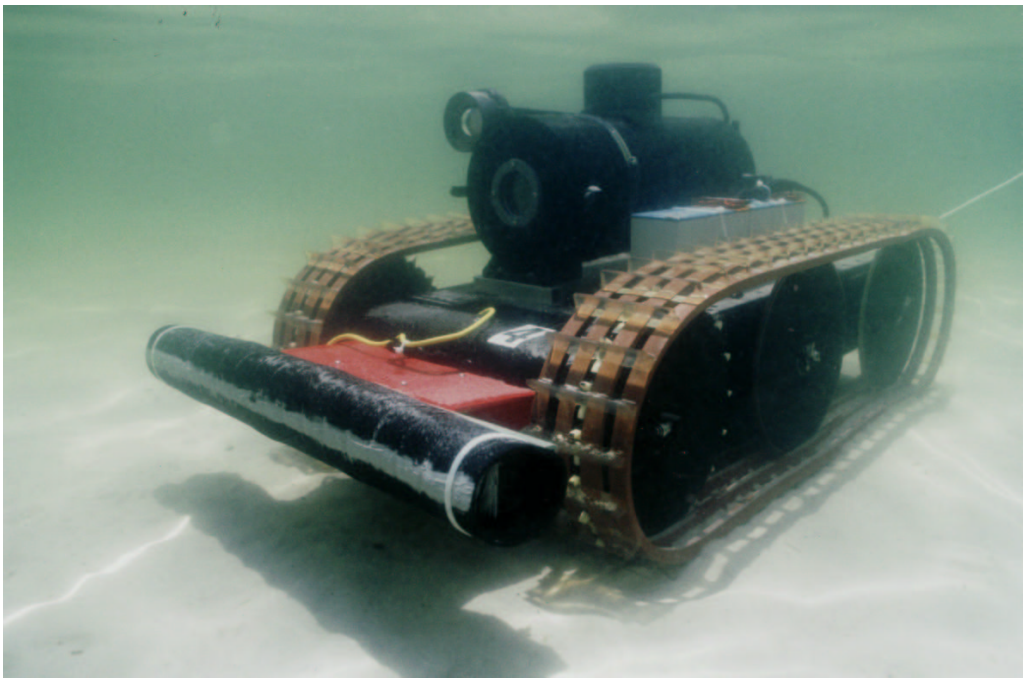


Figure 13. NSWC Coastal Systems Station demonstrated aspects of a mine-countermeasure (MCM) reacquire-identify-neutralize (RIN) mission using a Foster-Miller surf-zone crawler during an experiment near Gulfport, MS in October 2001. Telesonar modems provided a means for UUV remote control, sensor telemetry, and navigation. It is natural to envision seaweb coverage of an oceanic region from offshore waters, through the littoral, and into the surf zone in support of fixed and mobile autonomous systems. Such seamless wide-area networking is consistent with the Navy's need to support expeditionary operations in contested waters against the dual threat of submarines and sea mining. ***Photo courtesy of Chuck Bernstein, NSWC Coastal Systems Station, Panama City.***

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