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A Means to Networked Persistent Undersea Surveillance (U)

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Abstract

(U) The SSGNs entering service in 2006 provide an ideal platform for delivering a payload comprised of multiple distributed autonomous sensor networks in selected wide forward operating areas that will deny unmonitored movement of quiet diesel electric submarines. SSGNs have shown their potential for modular payload delivery and service as a command an control base station in exercises Giant Shadow in 2003 and Silent Hammer in 2005. Following on this success is an applied research program funded by the Office of Naval Research that is integrating more than a dozen demonstrated technologies to test and evaluate the merits of a prototypical, persistent, automated, tactically and environmentally adaptive sensor network. This network of fixed and mobile sensors and underwater communications nodes will employ advanced low-power signal processors for contact detection, classification, and localization and will exercise different levels of autonomy from a remote central controller including contact reporting, collaborative tracking, and contact hand-off to an adjacent sensor network. A plausible coupling of the SSGN and the sensor network payloads could help reduce the littoral Antisubmarine Warfare capability gap against the modern diesel submarine. This paper will present an overview of the ONR sponsored Persistent Littoral Undersea Surveillance, Networked (PLUSNet) program and provide a concept for equipping SSGN to deliver and operate the system of networked off-board sensors and vehicles.

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OVERALL SYSTEM DESCRIPTION AND OPERATIONAL CONCEPT

(U) In fiscal year 2005, PLUSNet, a multi-institutional program, was launched to develop and demonstrate a prototypical, semi-autonomous controlled network of bottom mounted and mobile nodes that implements, environmentally and tactically adaptive processing and enhances detection, classification, localization and tracking of quiet diesel electric submarines operating in shallow water environments typical of the Western Pacific.[2] A notional system grid consisting of multiple similar network cells of this nature would be distributed in a specified battle space, operate collaboratively, and could provide an ASW surveillance capability over an area on the order of 10^4 square kilometers. Individual cells could be viewed as autonomous wolf packs.[1]

(U) Under sponsorship of Dr. Tom Curtin of the Office of Naval Research, the program's participants include several academic institutions, businesses, university affiliated research centers, and Navy laboratories. Principal Investigators include Dr. Henrik Schmidt of MIT and Dr. William Kuperman of MPL/Scripps. Dr. Mitchell Shipley, ARL/Penn State, is the Program Manager. PLUSNet will integrate into a functioning networked distributed sensor system numerous component technologies that have, in some fashion, been demonstrated individually already. The principal challenges of the program will be to make individual components function more autonomously, communicate to other components efficiently and reliably, and operate collaboratively at both the local and field control levels. Node-to-node acoustic and node-to-shore acoustic/radio frequency gateway communications will enable both field-level and local collaborative control of the nodes within a single cell of an undersea networked grid with minimal operator intervention. The program will execute two sea trial experiments, one in August, 2006, and a second in the summer of 2007.

(U) Fiscal year 2005 was also the year the first SSBN-to-SSGN conversion was completed on the Trident USS *Ohio*. Entering service in 2006, this multi-mission submarine has the capacity to carry into forward areas and serve as a host ship to a number of autonomous networked cells analogous to the one being developed in PLUSNet.

(U) This paper describes the extended PLUSNet system, its concept of operations, and a concept for integrating the PLUSNet system aboard the SSGN. The SSGN payload integration work is not currently part of the ONR program but was conducted by Electric Boat with internal funds to provide early insights into common ship infrastructure that facilitates future mission capability aboard the SSGN.

1.1 THE BEGINNING OF AN UNDERSEA BATTLE GROUP

(U) An autonomous surveillance system, whose elements possess a range of intelligence, surveillance and reconnaissance capabilities, represents a potentially significant tool for ensuring U.S. access to denied areas, developing and sharing battle space knowledge (including over land), and enabling rapid offensive action with surprise. The ability of such a system to circumvent anti-access systems and operate in close proximity to an adversary by virtue of its stealthy elements provides an extension to the host ship's organic sensor capability. System scalability and ability to accommodate a variety of specialized, adaptable and affordable system elements will be necessary.

(U) Employing the distributed autonomous surveillance system network from a SSGN host ship has several strategic benefits including:

- The combination of a nuclear powered mother ship and persistent adjuvant vehicles could simultaneously cover several geographically dispersed areas during a single deployment. The adjuvant vehicles would be especially useful in shallow, crowded, or otherwise dangerous areas where the larger SSGN would be disadvantaged. Together, they could contribute more effectively to providing the persistent joint ISR necessary to deny adversaries a sanctuary in the littoral area.
- Dispersed networked systems are less vulnerable to current anti-access threats such as mines and quiet diesel-electric submarines because they are inherently smaller and quieter. They would be better able to penetrate denied areas to help ensure joint force access. Also, while these smaller vehicles could be highly aggressive, the SSGN could assume a less vulnerable posture while serving as forward command centers.
- This increased number of vehicles and nodes could significantly complicate an adversary's planning and response.
- As sensor capabilities migrate to off-board systems , the overall payload modularity of the submarine fleet increases. Future payload changes or upgrades would not take the host ship away from operational commanders increasing on-station time
- By continuously improving its undersea warfare capabilities through new technologies and CONOPS, the U.S. would create a widening gap that adversaries may not have the money to counter. They may also be deterred from using existing naval forces to engage in conflict.

1.2 TACTICAL SYNERGIES: A SUBMARINE DEPLOYED AUTONOMOUS SURVEILLANCE SYSTEM

(U) An autonomous surveillance system relies on stealth and proximity to key operational areas to achieve tactical benefits. The submarine deployment of such a system amplifies the strengths of the PLUSNet concept in a way no other deployment option can. U.S. nuclear submarines have unequaled stealth, endurance, and mobility among potential sea base host platform options. Stealth allows submarines to operate in close proximity to enemy shores without risk of political provocation or military action. The ability of the SSGN to deploy and service the system in a clandestine manner in proximity to key geographic areas is vital. Given the limited energy and speed of individual sensor elements, maintaining a stealthy posture in the operational area negates the enemy's potential advantage of speed. Also, submarines don't require logistic support or defensive escorts, something that all other host ship options would require. Moreover, the ability to quickly reposition submarines around the world with almost no logistic preparation provides significant employment flexibility. Finally, while operating submerged, submarines provide very stable, all-weather launch and recovery platforms from which to mount a reliable and persistent ISR campaign. Additionally, submarines are basically immune to cruise missiles, ballistic missiles, small boat attacks and even chemical, biological, and radiological weapons while other potential sea based platforms operating on the surface are vulnerable to these threats. The SSGN's relative immunity to attack not only allows it access to the littoral battle space denied to surface ships but also allows its payload to be dedicated entirely to offensive systems such as PLUSNet.

(U) Multiple off-board vehicles and stationary modules may enhance the SSGN's clandestine communications capabilities. Operating with the PLUSNet network, different elements of the system could serve as communications gateways for the SSGN improving it already stealthy posture. Conversely, inclusion of the SSGN within the local tactical network can at times mitigate the limited bandwidth and transmit power of smaller system elements within the network. Finally, the SSGN can serve as the local command and control node given it's organic processing power, communications capability and on-scene presence.

1.3 SSGN IS A REALITY

(U) Electric Boat is in the midst of converting USS *Ohio*, USS *Florida*, USS *Michigan*, and USS *Georgia* to SSGNs. *Ohio* was delivered to the Navy in November, 2005, and returned to service this past February 2006. All four SSGN ships will be operational by 2007 and together provide a 67 percent operational availability by using two crews to achieve a continuous, 2.4-ship deployed presence in support of Combatant Commanders' mission requirements.[2] Initially the SSGN will be equipped to support large-scale Special

Operations Forces (SOF) and launch cruise missiles. However, the Navy has committed to reserving two missile tubes on each ship for experimentation. Accordingly, two payload tubes are being specially modified to readily accept experimental payloads like a future PLUSNet system.

(U) The Navy has already begun the process of experimentation with the SSGN by using an SSBN as a surrogate. The first Navy Sea Trial “Giant Shadow” demonstrated the tactical benefits of deploying an organic network comprised of an off-board vehicle, unattended ground sensors and SOF personnel. Two years later, the “Silent Hammer” experiment conducted under the Navy’s Sea Trial program in October, 2005, demonstrated among other things, a new approach to payload integration. It used a Flexible Payload Module (FPM), designed and built by Electric Boat, to physically adapt new payloads to the ships existing missile tubes. This approach uses a new network based command and control system to facilitate communications between the ship and a wide range of payloads – even those not anticipated during design, such as the PLUSNet System. The full-scale FPM was designed, built and put to sea in only 14 months. FPM technology represents a new paradigm in payload integration. It was specifically developed to adapt a variety of weapons and unmanned vehicles such as those of the PLUSNet System to *Ohio* class ships.

1.4 PLUSNET – CONCEPT GENESIS

(U) Affordable diesel submarine technology provides an asymmetric threat to counter the Navy’s Sea Power 21 Sea Basing concept of secure, mobile, and networked sea bases. Air Independent Propulsion (AIP) submarine systems will be increasingly available with noise levels significantly lower than conventional propulsion plants.

(U) The operating areas of these new quiet threat submarines often consist of shallow water environments characterized by complex acoustic propagation conditions and high levels of anisotropic noise due to commercial shipping, fishing, biologics, and weather. To address the quiet undersea threat, a sensing system must be covertly deployed in days, operate for weeks to months, and adapt to in situ conditions to provide detection, classification, localization, tracking, and hand-off capability comparable to manned platforms.

(U) Legacy Navy system approaches have centered on Integrated Undersea Surveillance Systems (IUSS) that cue tactical platforms to reacquire, classify, localize and prosecute threat submarines. Although effective, this process is time consuming and man-power intensive.

1.4.1 A New Approach

(U) PLUSNet is the first step toward building an ASW capability that is scalable to regions of order 10^4 square kilometers, is easily relocated, and is potentially sustainable for months to years.[3] Long-term Navy investments in technologies such as unmanned undersea vehicles (UUVs), autonomous underwater vehicles (AUVs), in-node signal processing, compact sensors, environmentally adaptive sensor field approaches, as well as FORCENet connectivity, have enabled a change in the Navy's approach to ASW. An experimental PLUSNet system will be deployed in August 2006 that will operate as a distributed sensor field. It will involve mobile sensors, including AUVs, and fixed sensors that communicate by acoustic means and via RF gateway; transmit health and status reports from sensor nodes; continuously sample the environment; and adapt to tactical or environmental changes either locally or via field-level host ship or shore-based control. This new approach has the potential to reduce prosecution time and increase the effectiveness of the Navy's manned platforms.

(U) The PLUSNet system employs sophisticated numerical models that will use tactical and environmental data collected from the network to predict and optimize sensor performance, particularly for mobile nodes and their sensors. Competing mobile and fixed node demands arising from the various model recommendations for network adaptation to environmental conditions (for better sensing and acoustic communications) and to potential targets will require arbitration. Competing system needs will include maintaining adequate communications between network nodes, achieving the best sensor location and orientation for target detection, tracking, and hand-off, conserving component and overall system energy consumption.

(U) In addition to the new model driven approach, the PLUSNet program is addressing several of the long-standing challenges to developing a credible underwater surveillance system such as communications and power management. The PLUSNet program is developing an underwater and radio frequency gateway communication system including suitable message protocols for efficient data transfer around the network. Addressing the difficult problem of networked underwater communications is the principal thrust of the first PLUSNet sea trial experiment planned for August 2006. Achieving genuine persistence, on the order of months, with a complex autonomous surveillance system is another challenging problem being addressed by the program. Techniques to manage node and cell/grid response to targets and false alarms that can rapidly deplete component energy are targeted areas of research.

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[2] PLUSNet Objectives Document, M. Stewart, editor

(U) No less daunting are the challenging signal-to-noise ratios of the threat itself. The three-year PLUSNet effort will not solve all these problems. It will, however, demonstrate the feasibility of an autonomous networked approach to closing the ASW Capability Gap.

(U) The right mix of PLUSNet technology and manned ships will produce a much more efficient system. This new technology can serve as a force multiplier for the limited manned platforms in the theater of operation. The resources of the Navy's capital ships will be freed from wide area surveillance and now be focused on those phases of the mission where either the man-in-loop or massive technical resources are necessary.

1.4.2 PLUSNet Components

(U) To span and explore the domain of autonomous vehicle size, speed, and endurance, and sensor types, PLUSNet is bringing forth a wide assortment of components. Examples include large propelled vehicles bearing high-frequency panel arrays, small gliding vehicles bearing low-frequency towed arrays, mid-sized propelled vehicles carrying high and low frequency arrays, larger wing-shaped gliding vehicles bearing vector sensors and mid-frequency linear arrays, and bottom-mounted acoustic and electric field sensor arrays. This section lists the components of the hypothetical system and salient attributes. Sections 2 through 4 provide preliminary additional information where available. Graphical representations of most of the components appear in Figures 1 through 7. Mobile nodes and key attributes consist of:

- Seahorse AUV: Large UUV Passive Array (LUPA) Micro-Modem, CTD, 3-6 kt with potential drift mode, Figure 1.
- Bluefin/Odyssey AUVs: High frequency nose array, Towed low frequency vector sensor array (VSTA), CTD, Micro-Modem, 3-5 kt with potential drift mode, Figure 2.
- Seaglider AUV: single wide band hydrophone, vector sensor, CTD, Micro-Modem, 0.5 kt, Figure 3.
- Slocum glider AUV: low frequency towed hydrophone array, CTD, Figure 4.
- XRay glider AUV: Mid frequency leading edge array, vector sensor, CTD, Micro-Modem , Figure 5.

(U) The PLUSNet AUVs will provide the network persistent, responsive, controllable sensor coverage over a wide area. The Seahorse AUV, with the hull mounted LUPA, provides a platform that can easily drift while maintaining a sensing mode and has the payload capacity for either prime-energy or mission-related payloads. The Bluefin-21 AUV's buoyancy engine will allow drifting and bottoming modes of operation with the vector sensor towed array to afford vertical aperture and to conserve energy.

(U) The Seahorse AUV with its LUPA detection, classification, localization, and tracking (DCLT) sensor and processing will demonstrate persistence of the network by extending its already demonstrated 500 nmi range and multi-day endurance to 1 week of operation underwater utilizing autonomous behaviors including drifting. Bluefin-21 AUVs will provide the network persistent, responsive, controllable sensor coverage over a wide area. A buoyancy engine will allow drifting and bottoming modes of operation with the vector sensor towed array to afford vertical aperture and to conserve energy. Seagliders will be circulated around the operating area as the network communication backbone and for simultaneous ocean sampling. XRay is anticipated to demonstrate higher speed and load-carrying capacity as a glider in deeper water. The Slocum glider will employ an acoustic towed array.

(U) Fixed nodes consist of:

- Hydrophone array – vertical (“Kelp”): Micro-Modem
- Vector sensor array – horizontal: Micro-Modem.
- Electric field sensors: a model of the electric field sensor to be used in MB06 is shown in Figure 6.

(U) Kelp and the horizontal array will provide orthogonal apertures to enhance DCL and overall system sensitivity. They will likely gain initial detections to which mobile nodes are subsequently directed. These fixed nodes are a logical extension of existing Navy systems with the advantages of greater persistence, larger aperture, and better signal processing. These attributes counterbalance the liability of immobility.

(U) The composition of an operational cell of nodes will differ considerably from this prototype for several reasons including sensor coverage requirements (both physical and spectral), communications network requirements, and cell mobility requirements. PLUSNet experimentation will provide clues that will aid in developing a range of mission-specific cell compositions and methods for their employment. Optimizing cell composition and functions is the topic of on-going and future research.

(U) Host ship or shore components consist of the complex processors listed below. The first four provide at-sea node setting recommendations to the fifth. The interconnections between these components are shown in Figure 7.

- Environmental Adaptation
- Nodestar Tracker
- Optimal Search
- Optimal Communications
- Network and Field Controller

1.4.3 PLUSNet Objectives

(U) The PLUSNet program seeks to achieve signal gain and hence detection, classification, and localization (DCL) performance against quiet targets with the use of a grid of nested, distributed sensor networks that can adapt to local environmental and tactical conditions. The adaptive surveillance capability such a grid will provide consists of four stages. Stage 0 requires an ocean nowcast/forecast field and dictates preliminary location assignments for fixed and mobile components of a cell. In situ feedback on ocean environmental conditions come from mobile network nodes as does measured ambient noise and bottom geoacoustic inversion results. These inputs are combined with external signal clues, as available, to exercise local and field-level control of network nodes to accomplish Stage 1, “adaptive search.” As targets are detected, the feedback loop continues generating additional local and field-level control commands to enhance (adaptive) DCL – Stage 2, “adaptive DCL.” Once locked on-target, one or mobile nodes can optimally converge on that target – Stage 3, “adaptive convergence.”

(U) Each institution involved in the three-year PLUSNet program has set forth phased objectives[4] that will demonstrate:

- Ability of a field node (e.g., a fixed node) to pass data and commands via acomms to another field node (e.g., a mobile node), that relays the message to the host ship/shore-based component via RF comms.
- Ability of host ship/shore-based component to pass data and commands to a gateway field node via RF communications, which in turn relay the information to other field nodes.
- Ability to accurately sense the environment, predict acoustic performance, and adapt (redeploy) mobile nodes as a result to improve tactical and acoustic communication performance
- Ability to autonomously detect a high level target source, track the target, and forward contact/track information between nodes and to the host ship/shore-based component, and then
- Redirecting mobile assets toward the path of the target, achieving target reacquisition by acting in concert, and acquiring additional data for final classification and tracking, and, finally,
- Ability to process realistic target signatures by post-processing recorded data.

2 SEA SENSOR NODES AND SIGNAL PROCESSING: FIXED & MOBILE

2.1 FIXED: HYDROPHONE ARRAYS, ELECTRIC FIELD SENSORS

(U) Two distinctly different fixed hydrophone arrays and two identical electric field sensors are included in the prototype PLUSNet cell. ARL:UT will employ one of two 20-element vector sensor arrays manufactured by NUWC-Newport in a bottom-mounted horizontal configuration. SPAWAR Systems Center, San Diego will use Kelp, a 75 m, 64-element, vertical conventional hydrophone array. Both hydrophone arrays will connect to the acoustic communications network using Micro-Modems. APL-UW will employ two of their tri-axis electrical field sensors. In an operational system, these arrays and their associated processors are expected to provide initial quiet target detection and classification capability and initiate collaborative behavior of mobile nodes both directly and by way of a host ship/shore-based field control system described in section 3. Each fixed node of the hypothetical system will employ a Woods Hole Oceanographic Institute (WHOI) Micro-Modem for underwater communications.

2.2 MOBILE: CONVENTIONAL AND BUOYANCY-PROPELLED VEHICLES

(U) Several mobile sensors will be employed in the PLUSNet cell. At the expense of higher energy consumption, mobility affords these components important flexibility that fixed sensors lack. They can relocate to different operating areas to the degree permitted by local ocean currents; move about the battle space and measure the ocean environment and environmentally adapt to time- and space-dependent acoustic propagation path variations for tactical sensing and acoustic communications; and tactically adapt to achieve improved detection, classification, and localization of targets. Improvements in energy sources and development of energy-conserving behaviors will be relied on to achieve persistent surveillance with mobile nodes. Each mobile node of the hypothetical system will employ a WHOI Micro-Modem for underwater communications.

2.2.1 Bluefin-21 AUV

(U) The Bluefin-21 (Odyssey III) vehicle is approximately 15 ft long, 21 in. in diameter, displaces approximately 750 lbs, and is capable of operating to 200 m. It has a

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[3] PLUSNet Objectives Document, M. Stewart, editor
[4] MP06 Charter v2.5.ppt, T. Curtin

fixed combined RF (Freewave LAN) and GPS antenna mast. A unique pressure-tolerant lithium battery system drives a ducted propeller that can push the vehicle to 3 kt cruising and 5 kt top speed. Advertised endurance is 30 hours operating continuously at cruising speed. A high-frequency nose array, designed to work at 7 kHz, will be employed on one vehicle. MIT-developed signal processing, based on the Multi-Objective Operating System (MOOS), will be used to perform target DCL and tracking and generate contact, track, and vehicle health reports. Reports will be sent by acoustic modem into the undersea acoustic network.

(U) A 100 m low frequency (<1 kHz) vector sensor towed array behind a second Bluefin-21 will use a newly designed buoyancy engine and quiet tail-cone assembly. The buoyancy engine, developed by Bluefin Robotics, Inc., coupled with a low-power operating mode, will permit this vehicle to operate in a drifting mode allowing the slightly buoyant array system to achieve varying degrees of vertical aperture. In drift mode, the array will be quasi-vertical, and with the vehicle bottomed, the array will be essentially vertical. These behaviors will save propulsion energy, reduce vehicle self noise further to improve array SNR, and afford arrival path target classification clues using algorithms being developed by SAIC. In the drift mode, this Bluefin model will be able to take advantage of a “conveyor belt” of ocean littoral currents in which surface currents are flowing in one direction and deeper waters are moving in opposition. This phenomenon is typical of many littoral areas. The Scripps-MPL-developed quiet tail-cone consists of a low-noise, direct-drive propulsor tuned for low-speed operation to improve low frequency acoustic sensing.

(U) The two Bluefin vehicles combine acoustic sensing capability with mobility, facilitating adaptive search behaviors under both fully autonomous and supervisory control. Control algorithms will use vehicle mobility to assist with contact classification, particularly with respect to depth. For example, each vehicle could act as a surrogate cluster to demonstrate inter-cluster hand-off. One vehicle could detect the approach of an acoustic source. After forming a preliminary track estimate, this first vehicle would hand-off its estimate to the second vehicle not in contact with the target. The second vehicle would adaptively converge on, re-acquire, and classify the target.

2.2.2 Seahorse: Applied Research Laboratory – Pennsylvania State University (ARL/PSU)

(U) ARL/PSU in conjunction with ARL University of Texas (ARL:UT) is providing a detection, classification, localization, and tracking node using the ARL/PSU Seahorse AUV as the platform and the ARL:UT Large UUV Passive Array (LUPA) as the sensor. The Seahorse AUV is 28 ft long, 38 inches in diameter and weighs approximately 5 tons and is capable of operating at depths up to 1000 ft. With a full-compliment of batteries, the

Seahorse AUV has a demonstrated range of 500 nmi running at 4 kt with a maximum speed of 6 kt.

(U) The ARL:UT LUPA is a high frequency billboard array based on components of the Low Cost Conformal Array (LCCA) used on submarines. The LUPA will be mounted on both the port and starboard side of Seahorse for maximum coverage. DCL processing extends the work performed in the APB/ARCI process. The processing components of the LUPA will be housed in one of the Seahorse payload tubes.

2.2.3 Seaglider: Applied Physics Laboratory – University of Washington (APL-UW)

(U) Four Seaglider AUVs will be employed both as environmental sampling instruments and as a communications backbone including RF/acoustic gateway capability. Micro-Modem based acoustic communications will be integrated into the glider control system. When a glider receives an urgent acoustic message that needs to be sent ashore, it will alter its flight profile to surface and transmit as quickly as possible. The gliders will carry omnidirectional hydrophones that will be used to monitor and compare the ambient noise field over the three-dimensional operating area.

(U) The Seaglider's Micro-Modems will operate at 25 +/-2 kHz despite greater propagation loss. This frequency range was selected to take advantage of the anticipated reduced noise in that band. 80-bps transmissions using a frequency-shift-keying (FSK) mode of operation are standard. An additional microprocessor to be used aboard certain underwater nodes will permit receipt of various pulse-shift-keying (PSK) modes that all nodes will be able to transmit. Throughput on the order of 2.4-kbps is feasible although bit error rates will likely be higher. Four or five distinct Compact Control Language (CCL) message formats are being developed to standardize communications between underwater nodes. Underwater communications are addressed in more detail in Section 4.

2.2.4 XRAY: Marine Physics Laboratory, Scripps Institute of Oceanography, APL-UW

(U) The Office of Naval Research funded the development of a new-design undersea glider with greater speed and payload capacity. The Scripps Marine Physics Laboratory, working with APL-UW, designed and flew in 2005 a prototype wing glider that achieved speeds of about 7 kt and a glide ratio of 17:1 during ascending trajectories. More modest speeds and payload carrying capacity characteristics are expected for a fully capable glider system being developed. XRay will conduct basic operating trials in FY06.

2.2.5 Slocum Glider With Towed Array: SPAWAR Systems Center, San Diego (SSCSD)

(U) SSCSD has developed a ~10-m, 16-element low-drag array that can be towed behind a glider. The vehicle/array system will collect and process data analogous to the Bluefin-21 vehicles described above, will support collaborative behaviors to enhance adaptive environmental sampling and sensing, and will support a undersea communications network.

2.3 IN-NODE SIGNAL PROCESSING: ARL:UT, SCIENCE APPLICATIONS INTERNATIONAL CORPORATION (SAIC), HEAT, LIGHT AND SOUND, INC. (HLS)

(U) The PLUSNet concept takes advantage of and extends recent work in automatic target detection and classification that has been done in the APB/ARCI program. In addition, it will use sophisticated compression technology to reduce bandwidth requirements. These technologies are essential to eliminate inter-node cables and/or continuous RF communications that would otherwise be required to move data to a processing and analysis facility.

(U) Knowledge of the environment and of actual and potential targets collected by network nodes, and information from adjacent cells, is needed within a network to accomplish the stages of adaptive surveillance. This knowledge must be developed within each node by processing measured data and telemetered data arriving from the undersea and ashore network. Minimizing false-alarm rates will challenge such an automated system.

(U) The new vector sensor used in two arrays planned for PLUSNet affords a new level of array element localization. PLUSNet will combine SAIC-developed element localization and target motion analysis techniques, making use of three-axis velocity from each sensor, with adaptive beam forming, broadband detection and tracking, and additional processing for narrowband and broadband classification developed by HLS. Array element localization will be especially useful for towed sensor arrays.

(U) The towed vector sensor and the Kelp array will offer vertical apertures from which to estimate target depth. Processing of data from a range of sensors from low to high frequency regimes using coherent and incoherent methods, including a variety of rapid ranging and depth estimation algorithms (wave front curvature, surface/bottom reflections, matched field processing (MFP),) and kinematics and invariants processing is planned for this program.

3 HOST SHIP / SHORE NODES: NETWORK FIELD CONTROL FUNCTIONS

(U) A block diagram of the five host ship/shore-based components of PLUSNet is shown with inter-connections in Figure 7. Four of the components take inputs such as temperature and salinity versus depth, environmental model outputs, and target contact information. They also will track information such as acoustic node communications effectiveness from nodes in the autonomous sensor field. These components then generate suboptimal mobile platform movement recommendations to the fifth component, the Network and Field Controller. This component arbitrates from among the recommendations. These components are described in more detail below.

3.1 DATA FUSION, CLUTTER REDUCTION, TRACK BEFORE DETECT: METRON, INC.

(U) The Likelihood Ratio Detection and Tracking (LRDT)/Nodestar system will fuse information from a network of environmental and tactical sensors to help distinguish submarine from surface target and foe from neutral target. This will help produce a clear tactical picture. Nodestar and LRDT will produce probability maps to show where in the battle space sensors need to be allocated to improve detection and localization or to provide extra effort in areas with poor coverage. Working in conjunction with the Network and Field Controller, this component will generate detections and tracks based upon cross fixing and range and depth information. Track-before detect and data fusion methods developed in the Robust Passive Sonar program will be applied.

3.2 ENVIRONMENTAL ADAPTIVITY TO REDUCE ENVIRONMENTAL UNCERTAINTY: MASSACHUSETTS INSTITUTES OF TECHNOLOGY (MIT)

(U) Advances in robotics and underwater communication are causing a paradigm shift from platform-centric to net-centric, distributed sensing systems. The PLUSNet cell will enable nested, collaborative, and adaptive sensing and processing concepts in both active and passive regimes, though it will operate in passive mode only, as well as acoustically focused oceanographic sampling. Nodes need to be able to operate with intermittent or no connectivity, hence need for distributed sensing, processing *and* control.

(U) MIT will employ MOOS software to accomplish two principal functions, one ashore, the second at sea: 1) direct AUVs automatically within an operating area to sample and thereby reduce the uncertainty of the Harvard-modeled environment[5, 6] and 2) direct AUVs to track and conduct motion analysis on a potential target, including application of collaborative behaviors between adjacent mobile sensors. These behaviors will be constrained by factors such as avoiding obstacles, AUV energy state, cell sensor coverage requirements, and the need to maintain a functioning communications network.

3.3 ENVIRONMENTAL ADAPTIVITY TO OPTIMIZE MOBILE SENSOR SEARCH PERFORMANCE: APL-UW

(U) APL-UW-developed algorithms will ingest mobile node location and a modeled high-resolution range-dependent environment and determine where to send vehicles/sensors such that its acoustic field performance metrics are maximized. These constrained optimization problems require vehicle operating dynamic characteristics; range-dependent sound speed profiles; ocean velocity fields; computed, measured, or estimated transmission loss; ambient noise; source level; array directivity versus frequency to determine the ratio of signal excess to probability of detection; and bathymetry/operating area (cell size) limits. Improving probability of detection reduces probability of target presence. Metron’s Nodestar tracker will be used in conjunction to assess presence of target tracks.

3.4 ENVIRONMENTAL ADAPTIVITY TO OPTIMIZE MOBILE NODE DISTRIBUTION TO SUSTAIN COMMUNICATIONS NETWORK: HLS

(U) Realistic time-series acoustic communication signals from multiple platforms including path-dependent Doppler for moving vehicles have been simulated by HLS. This will support predicting acoustic communications performance and hence basic mission planning. It will be used to develop mobile node behavior algorithms that optimize the communications grid in a range-dependent acoustic environment.

3.5 NETWORK AND FIELD-LEVEL CONTROL AND THE COMMON PICTURE: ARL/PSU

(U) The Network and Field Controller (NAFCON) receives recommendations for mobile sensor redistribution from each of the preceding four components. The NAFCON arbitrates from among these recommendations given additional constraints such as node and field energy state, knowledge acquired external to the cell, and priorities established by operators in the command and control loop. The controller will, among other things, determine when mobile node adaptation is needed, what parameters to adapt, and what to do if adaptation is needed but assets are not available (e.g., suboptimal adaptation).

(U) Most information in the PLUSNet system will be pushed. NAFCON will monitor for cases in which additional information needs to be passed between field nodes and attempt to pull that information. It will assess if the node(s) in question is/are capable of communicating due to environmental or other conditions, and what those conditions are. For example, new environmental data may have been received that does not affect the node positions or settings. Though there is new data, it may be unnecessary to pass. If covert operations have been invoked, NFC will know to restrict communications.

(U) Drawing on data from throughout the undersea network, the NFC will have the information required to build the best common picture of the battle space.

4 UNDERWATER AND RF GATEWAY COMMUNICATIONS

(U) A networked communications gateway system that combines underwater acoustic and radio frequency is necessary to realize the PLUSNet system. WHOI has developed and employed their Micro-Modem hardware and software to achieve local, simple point-to-point communications using a master-slave scheme and FSK and various PSK modes. PLUSNet will build on this baseline capability including expansion of modulation and demodulation techniques, different network architectures, and the flexibility to work with multiple mobile nodes including profiling gliders. Prediction and modeling of communication links and network performance is crucial to this development.

(U) The results of largely post-processing analysis from the FY06 experiment will provide a solid basis for developing mobile gateway and mobile node track recommendations to sustain satisfactory network inter-cluster and intra-cluster communications. These track recommendations should be available for manual insertion in the Network and Field Control component in FY07. WHOI and HLS, Inc., will jointly implement a reliable, small-scale communications network for fixed and mobile platforms for the FY07 experiment.

4.1 COMMUNICATION NEEDS

(U) Data streams as small as a few dozen bytes but potentially as large as hundreds of megabytes will be generated by underwater sensing network nodes to pass environmental, platform health, various levels of target data, and vehicle commands around the battle space. In-node processing will be necessary to consolidate volumes of data that will accumulate to constrain the quantity of data that must be routinely transmitted. Higher sample rates necessary for working with high frequency signals and the periodic need to send time series data into the network contribute to the problem.

(U) Compact Control Language (CCL) was developed by WHOI to make efficient use of limited acoustic bandwidth available to AUVs. CCL is a set of standard, discrete, small message formats on the order of 32 bytes that includes AUV commands and data formats for typical sensors. PLUSNet will use a CCL message framework within its communications network.

(U) The greatest stressor of the PLUSNet communications system will arise from network reaction to a false target alarm rate. Improving field adaptivity to the environmental and tactical situation will help improve SNR and reduce the false alarm rate. Improving autonomous DCL capability of network nodes will reduce communication requirements that bring other sensors and, via gateway, humans into the loop.

4.2 MICRO-MODEM: A COMMUNICATIONS TECHNOLOGY: WHOI

(U) A fully capable WHOI Micro-Modem consists of a TI-5416 DSP main board working with a TI-6713 based co-processor. The modem implements an adaptive decision feedback equalizer with integrated Doppler and error-correction to afford 80-bps frequency-hopped-FSK mode communications. Various PSK-mode data rates have been achieved between 300 and 5000+ bps, depending on the acoustic channel.

(U) Up to 16 subnet nodes, including fixed, mobile, and mobile gateway elements, within a single network are possible with the current system. Half duplex broadcasts are typically issued from a controlling node that initiates transmissions with a TDMA-controlled mini-packet. The leading mini-packet declares which node will transmit and what the data rate will be. “Sleep” and “ping with ranging” are examples of other mini-packets that can be employed.

4.3 HF GROUNDWAVE RF COMMUNICATIONS: ARL:UT

(U) ARL:UT has developed an HF radio capability that will be applied in the PLUSNet system for medium distance over the horizon communications approaching 100 nautical miles. It may be feasible to integrate this capability into the glider-based RF/acoustic gateway system for remote network/SSGN connectivity.

4.4 COMMUNICATIONS SECURITY CONCERNS

(U) The recognition differential of human and automated processing systems is frequently improved when characteristic time series data is available. The size of these time series data makes it difficult to send over an acoustic network. Additionally, false alarms will likely place a burden on communication volume within an automated network system and on network energy consumption. The need to “chat” often and sometimes for a long period poses inherent system security vulnerabilities and demands consideration of low-probability of intercept/low probability of detection (LPI/LPD) communications techniques. These are being investigated within the PLUSNet program.

5 PLUSNET INTEGRATION OPTIONS ABOARD THE SSGN

(U) This study provides a first look at the possibilities and limitations associated with

SSGN integration to the PLUSNet system designers. The goal of the Electric Boat internally funded study was to provide an efficient means to load, stow, launch, and recover all the elements of the PLUSNet system. Early consideration of the host ship capabilities may provide technical and operational options not previously considered by the system designers. Additionally, consideration of launch and retrieval operations early in the program will aid in a smooth transition through test and evaluation to the operations in the Fleet.

(U) The SSGN has several submarine ocean interfaces that can be used to launch and recover payloads. Figure 8 illustrates the available SSGN ocean interfaces. The largest interface, the D-5 missile tube provides an exponential increase in potential vehicle size. The D5 will be the focus of this study. The SSGN missile tubes also offer significantly more volume than available in the torpedo room. A single complement of SSGN missile tubes can house as much as twenty attack submarine torpedo rooms.

5.1 BENEFITS OF SSGN MISSILE TUBE INTEGRATION

(U) Historically, whenever possible submarine deployed payloads have been stowed within the ship prior to launch to provide a benign a stowage environment and to allow personnel access for maintenance and repair. The principal ocean interface for submarine deployed systems has been the torpedo tube. But vehicles and systems constrained to fit within a torpedo tube have limited endurance and capability. Deploying systems larger than torpedoes has typically required that they be carried topside on the submarine in either a pressure-proof hangar or fully exposed to the sea. Topside mounted systems are exposed to the same severe forces that the submarine must endure: loads imposed by depth, speed, maneuvering, and shock. Having these payloads meet such requirements often results in systems that are heavy and expensive.

(U) Placing a vehicle in a topside hangar can relieve the burden of meeting such requirements on the vehicle, but imposes them on the hangar. Additionally, whether the vehicle is topside with or without a hangar, restrictions on the speed and maneuverability of the host submarine will result which is operationally undesirable.

(U) Having the vehicle inside the molded lines of the hull in a pressure-proof enclosure eliminates these concerns. Carrying such vehicles in the SSGN missile tube eliminates such requirements and provides the largest volume for the vehicle or payload system. Furthermore, payload tube stowage allows the payload to be designed to a shallower depth than the host submarine if the mission allows. Finally, the SSGN missile tubes do provide for limited manned access as well as transfer of material between tubes or ship spaces.

5.2 SSGN MISSILE TUBE CONFIGURATION

(U) The D-5 payload tube of the SSGN is the converted missile tube of the *Ohio* Class submarine (SSBNs). It was originally designed to carry the Trident D-5 missile and has been modified through the SSGN conversion program to support the use of missile tubes as lockout chambers, for SOF stowage, and for Multiple All-Up Round Canisters (MACs), which each contain seven Tomahawk cruise missiles. Missile tubes 1 and 2 are being permanently converted to lockout chambers. The remaining tubes (tubes 3 through 24) are being modified to accept MACs. Of these 22 tubes, 8 (tubes 3 through 10) can also accommodate SOF stowage in place of MACs. Because of the lighter weight of MACs and SOF stowage in comparison to D-5 missiles, permanent ballast cans are installed in all tubes except tubes 9 and 10. Thus, tubes 9 and 10 can provide the longest usable length for new payload systems. Additionally, tubes 9 and 10 (as well as tubes 5 and 6) have 30 in. diameter access hatches on the first platform. For purposes of this study, it is assumed that the PLUSNet system elements would be stowed in either tube 9 or 10 to facilitate personnel access into the payload tube.

5.3 A UNIVERSAL LAUNCH AND RECOVERY MODULE (ULRM) FOR THE SSGN

(U) Electric Boat assessed the feasibility of using a Universal Launch and Recovery Module (URLM) housed within the SSGN missile tube for support of the PLUSNet system. Previous work conducted at Electric Boat [7, 8] have developed a concept design for a Universal Launch and Recovery Module for the SSGN that allows a wide variety of payloads to be stowed, launched, and retrieved from an submerged SSGN. The ULRM concept development is an effort to identify the ship infrastructure that will enable a wide variety of off-board payloads to be rapidly integrated and fielded. Past payload integration work has shown that a common challenge to fielding new off-board systems is the launch and recovery operation. Electric Boat undertook this study to investigate if the URLM concept is extensible to the PLUSNet system.

(U) The study considered it desirable to house both the launch and recovery (L&R) mechanism and the PLUSNet system elements in the same payload tube. This would have the least effect on the ship, simplify the L&R mechanism, and present an approach that is scalable through the use of multiple SSGN missile tubes. It would not sacrifice other potential payloads, which the host ship could carry in other tubes.

(U) The goal of the ship-based payload module was to minimize the operational impact on the ship while maximizing payload capability and interchangeability. A series of trade studies conducted by Electric Boat resulted in a ULRM that is housed inside a canister structure, which is installed in the missile tube. The ULRM concept has been developed with sufficient detail to establish technical feasibility and to determine the maximum practical space available for payloads such as the PLUSNet elements. The ULRM has the following benefits:

- Maximizes the size and variety of payloads that can be accommodated
- Minimizes ship operational constraints (speed, depth, sea state) during L&R operations
- Minimizes complexity of the L&R mechanism
- Minimizes quantity and complexity of L&R to payload interfaces
- Minimizes potential collision between the deployed payloads and the ship

(U) The URLM is shock isolated from the ship structure and constrained within the SSGN missile tube. Ship services such as power and data are provided to the URLM through standard tube penetrations. Access to the payload module is possible through the upper and lower tube access hatches of the Payload Missile Tube. The ULRM design study concluded that the largest payload that could be accommodated was a right circular cylinder 5.5 ft in diameter and 25 ft long with a corresponding dry weight of 20 LT. The estimated weight of the tube mounted ULRM, not including payload, is approximately 60,000 lbs.

5.3.1 ULRM Operation

(U) The ULRM provides a practical means to transition payloads from the stowed condition within the missile tube to “prepared for launch / recovery” position 12 ft above the missile deck. The ULRM has the capability to rotate vertically stowed payloads to a horizontal attitude while still locked in the payload cradle. The ULRM has the capability to accept a wide variety of payload specific cradles that may be specially designed. Using this approach, design modifications required for ship integration of specific elements of the PLUSnet system are limited to the ULRM cradle assembly.

(U) Figure 9 illustrates the principal components of the ULRM. The ULRM consists of an outer canister that interfaces with SSGN missile tube. Within the outer shell is the hoist mechanism and cradle assembly. Additional vehicle or equipment stowage cradles can be located alongside the main recovery arm. The hoist mechanism is powered by an external hydraulic power pack that is located at the base of the ULRM. Additional payload support equipment such as battery charging equipment can be located within the ULRM. The ULRM is a derivative of the Flexible Payload Module (FPM) program and leverages the network based connectivity to the SSGN as well as the self contained onboard command and control system and power management system.

(U) Figure 10 is a time series of a typical deployment and retrieval operation. For deployment and retrieval operations the SSGN is assumed to be between 150 ft and 200 ft keel depth. Submarines generally do not conduct operations between 150 ft and periscope depth due to ship safety concerns (surface ships, floating and semi-submerged debris, etc.). The SSGN missile tubes are designed for routine operation at 200 ft keel depth or less.

(U) Additionally, launch and recovery operations will be done with the ship in hovering mode. The SSGN hovering system will control the ships depth to within ± 5 ft in sea state (SS) 3. In a hovering posture the ship's velocity relative to the water is nominally 0 kt. However, surface waves will cause local velocity gradients that affect both the payload and ship motions.

5.4 PLUSNET ELEMENT INTEGRATION

(U) A tactical cell of the PLUSNet system being developed under the current program consists of the following elements:

- Seahorse AUV: Large UUV Passive Array (LUPA), CTD, drifting behavior
- Bluefin/Odyssey AUV: High frequency nose array, towed low frequency vector sensor array (VSTA), CTD, drifting behavior
- Seaglider AUV: single wideband hydrophone, vector sensor, CTD,
- Slocum glider AUV: low frequency towed hydrophone array, CTD
- XRay glider AUV: Mid frequency leading edge array, vector sensor

(U) Fixed nodes consist of:

- Hydrophone array – vertical ("Kelp")
- Vector sensor array – horizontal
- Electric field sensors

(U) The PLUSNet The SSGN installation occupies five SSGN missile tubes. The integration approach taken and recommendations for each system element are provided below. The integration of the Network and Field Controller, supporting numerical models, and support staff was not investigated as part of this study. The space and power available in the reconfigurable SOF / Mission Planning Center should easily meet the needs of the PLUSNet system. The integration approach taken and recommendations for each system element are provided below.

5.4.1 Seahorse UUV Integration

(U) During the SSGN experiment "Giant Shadow" conducted in January 2003, the Seahorse UUV was deployed from the USS *Florida*. This experiment successfully demonstrated the feasibility of *launching* a large UUV from a D-5 payload tube. The

Seahorse vehicle is 38 in. in diameter and 28’ long, and weighs about 10,000 lbs. Therefore, this task focused on the operational environment for *recovery* of the LUUV. The ULRM allows the Seahorse to launch and recover in a horizontal attitude consistent to current seahorse operations. The ULRM provides a three-foot-diameter docking cone and docking transponders to allow the Seahorse to dock in a manner similar to the current LMRS program, which has recently demonstrated successful homing and docking operations.

(U) The arrangement of the Seahorse in the stowed position within the SSGN tube shows the limited space available for manned access. Replenishment operations may be limited to the areas directly accessible by the first platform missile tube hatch or through remotely controlled operations. The arrangement study also shows that the next generation Large Displacement UUV used for this operation could be 5.5 ft in diameter and up to 25 ft in length and 9 LT in displacement. This represents over a 100% increase over the existing Seahorse UUV. See Figure 11.

5.4.2 Bluefin-21 Integration

(U) The Bluefin-21 is a highly maneuverable 21 in. powered UUV which has demonstrated controlled homing and dock maneuvers. The Bluefin-21 would be launched and recovered using the ULRM configured missile tube. A preliminary arrangement study indicates that multiple Bluefin-21s can be stowed within the ULRM as shown in Figure 12 Up to six (6) Bluefin -21s can be housed within a single URLM with two vehicle being stowed on the launch and recovery cradle and four vehicles in secondary vertical stowage cradles. The ULRM concept developed for these heavy weight UUVs allows manned access to a work platform and vertically stowed vehicles within the missile tube. The work platform and supporting equipment will allow replenishment, maintenance and repair operations to be conducted. Individual vehicles can be moved from their stowage locations to the launch and recovery cradle. For the Bluefin -21 with the towed array, a separate array deployment canister that is mounted aft of the UUV on the cradle is recommended. The array canister will ensure that the stowed cable deploys reliably as the vehicle swims off the cradle and away from the ship. Once the cradle is returned to the stowed position and the missile tube is drained after launch the canister can be removed. Recovery of the vehicle and array presents a unique challenge. If array costs are modest, the array could be jettisoned prior to recovery.

5.4.3 Seaglider / Slocum Glider Integration

(U) The small size and portability of the Seaglider presents several stowage options aboard the SSGN. The Seaglider buoyancy driven propulsion system will likely be sufficient for a safe launch from the ship but may limit the recovery approaches used. Initial arrangement concepts indicate that the ULRM concept could deploy two Seaglider UUVs in a single launch cycle. The launch cradle would be extended from the ship and individual Seagliders would be positively ballasted and then released from the launch cradle. The launch evolution could be accomplished with the ship in a hovering posture to minimize ship generated flow disturbances.

(U) Recovery of the Seagliders may be accomplished using a capture cone or tail hook configuration with the SSGN in a hovering posture. Should the Seaglider control system be unable to accomplish the docking maneuver, a ship deployed Remotely Operated Vehicle (ROV) could be used to recover a stationary vehicle. An ROV retrieval concept is currently being developed for the DARPA funded Multi-Purpose Unmanned Aerial Vehicle (MP-UAV) program. The MP-UAV is an SSGN launched and retrieved UAV, which employs an ROV to connect a recovery line to a floating aircraft [9]. Similarly, an SSGN deployed ROV could connect a retrieval line to surfaced Seaglider for retrieval onto the ULRM cradle. See Figure 13.

(U) The small size and weight of the Seaglider allows several stowage options aboard the SSGN. Using only the payload space within the ULRM, six Seagliders can be stowed along with the two Bluefin-21s as shown in Figure 12. To increase stowage efficiency the mid-ship wings and antenna assemblies should be removable. In preparation for launch the Seaglider would be moved and secured to the launch cradle using the in-tube davit. The fins, antenna assembly and towed array module would be installed manually. A second stowage option available is to store the Seagliders in an adjacent missile tube. Special Operations Forces (SOF) stowage modules have been built for the baseline SSGN program and allow a wide range of equipment to be stored in the missile tube with manned access for retrieval of equipment into the ship. Initial arrangement studies indicate that a reasonable logistics path exist to permit transfer of the Seagliders from the SOF stowage module into the ship and then into the ULRM equipped tube. This approach would leverage the existing SOF stowage canisters to increase the ship's complement of Seagliders to 18 vehicles, while allowing for 6 Bluefin-21s to be stowed within the URLM canister. Figure 14 shows the planned logistics path and stowage arrangement.

5.4.4 XRay Glider Integration

(U) Integration of the XRay Glider into an SSGN ULRM was assessed. The ULRM concept is well suited to integration and launch of the XRay concept. The initial integration study placed the vehicle in the tube vertically without the need to fold the wings or control surfaces. A specially modified ULRM cradle will be required that interfaces and adequately supports the XRay vertical to horizontal transition. The initial arrangement assessment suggests that the vehicles wingspan can be increased to a maximum of 25 ft. while the chord or length of the vehicle is limited to 5.5 ft.

(U) Launch of the XRay appears feasible by placing the SSGN in a hovering posture and using the vehicle's buoyancy engine effect and athwart ship lift-off from the cradle. To facilitate the launch a simple catapult integrated within the cradle could be used. Recovery of the XRay may be accomplished using an ROV to secure a retrieval tether to a surfaces and stationary vehicle as described for the Seaglider. Given the developmental nature of the current vehicle, the feasibility of an "in-flight" docking to the ULRM recovery arm was not investigated.

5.4.5 Fixed Array Canister "Kelp Array " Integration

(U) Fixed sensor arrays are a primary component of the PLUSNet system. Given the experimental nature of the program, the configuration of the tactical system remains uncertain. For logistical reasons, it is recommended that these systems be packaged in easily handled canisters. It would also be advantageous to develop a standard deployable package that would support several different fixed sensor systems.

(U) For the purpose of this initial study, Electric Boat chose a right circular cylinder as a common array canister. The sensor canister considered is 21 in. in diameter and 48 in. in length, enclosing a volume of approximately 19 ft^3. Assuming that the canister would be negatively buoyant for deployment to the bottom, individual canisters may weight on the order of 1,500 lbs. This packaging concept allows commonality with the 21 in. UUV cradles, lifting and handling infrastructure. An alternate standard packaging concept would adopt a standard 55 gallon shipping drum, which has nominal dimensions of 22.5 in. diameter and 34 in. in length. Multiple drum sections could be combined to provide needed volume. This approach leverages existing transportation infrastructure and presents a ubiquitous object to the enemy once deployed.

(U) Deployment of the sensor canisters may be accomplished using the ULRM mechanism with a modified cradle. The sensor cradle would have the capability to rotate athwart ship to allow the sensor canisters to be released over the side of the ship and sink to the sea floor. Figure 17, depicts this deployment scheme. Further analysis need to determine the trajectory of the released canisters as function of ship speed, canister weight and cradle configuration.

6 OPERATIONAL SCENARIO: LAUNCHING PLUSNET CELLS

(U) Mission planning for employment of a grid of PLUSNet cells will be complex. Operators will consider many factors affecting the employment and performance of fixed and mobile sensor systems including four-dimensional acoustic and nonacoustic propagation estimations, ocean current distributions, threat characteristics, expected threat approach axes, sensor capabilities, component, cell, and grid energy considerations, insertion and standoff risks to the host ship, and attrition estimations. These considerations will affect network node location, orientation, and density within the cell, required proximity and connectivity between the network cell and the host ship, and expected node-reseeding and recharging periodicities.

6.1 INGRESS: BATTLE SPACE PREPARATION

(U) The first components to be launched by the SSGN will be the communications backbone and environmental sampling network consisting of undersea gliders. These mobile nodes will autonomously sample water column sound speed and monitor acoustic characteristics (acoustic communications propagation, ambient noise levels in multiple bands, range-dependency) and ocean currents in the battle space. They will telemeter results acoustically and via RF to the nearby host ship and thus confirm network connectivity. If host-ship risk is elevated, these mobile nodes can be launched over-the-horizon (OTH) and be monitored on the host ship via RF channels only.

6.2 LAUNCHING FIXED NODES AND MOBILE NODES

(U) Mobile nodes will be launched to acoustically sanitize the cell area of hostile submarines and further characterize the acoustic battle space. As with the gliders, if host-SSGN risk is elevated, these mobile nodes may be launched OTH. Thereafter, provided risk to the host-ship is reduced, the SSGN will enter the cell area to launch fixed nodes. Connectivity between moving and fixed nodes will be affirmed by the SSGN before the ship departs the cell area for its remote station or seeding of another PLUSNet cell.

6.3 MONITORING AND MAINTAINING THE CELL

(U) SSGN will monitor the health of individual cell nodes passed via HF Groundwave RF communication or acoustic communications provided paths are established for this. As more is learned about conditions within the cell operating area, nodes may autonomously adapt to the changing environmental or tactical situation. Alternatively, SSGN “Network Field Control” may remotely direct network adaptation. As nodes reach their energy-end-of-life, they will either be called to the SSGN remote station or the SSGN will re-enter the cell area to effect rendezvous, recovery, and recharging operations. Lost nodes may be similarly replenished.

(U) Upon launching of the first cell, the SSGN can proceed to another cell lay-down area to launch another cell within the grid. Environmental conditions, anticipated threat characteristics, and grid size will determine the number and distribution of cells that must be deployed. SSGN carrying capacity will dictate the number of cells that it can carry. Upon mission completion, the SSGN will maneuver to recover network nodes in condition to be overhauled and return to base. The ability to recover the fixed arrays with the system's ROV module requires further consideration. The limited capabilities of the ROV may limit recovery operations to high value components.

7 SUMMARY

(U) The SSGN appears to be a viable means for inserting and operating with the evolving autonomous ASW surveillance system capability represented by the ONR-funded Persistent Littoral Undersea Surveillance System, Networked (PLUSNet). The synergistic combination of host SSGN with a largely autonomous distributed multi-component "payload," comprised of cells of mobile and fixed sensor nodes using low-power signal processors for contact DCL and autonomous control that are capable of underwater acoustic communications supporting a mobile acoustic communications backbone, has the potential to reduce the fleet's ASW capability gap. An autonomous surveillance system, whose elements possess a range of intelligence, surveillance and reconnaissance capabilities, represents a potentially significant tool for ensuring U.S. access to denied areas, developing and sharing battle space knowledge (including over land), and enabling rapid offensive action with surprise. The ability of such a system to circumvent anti-access systems and operate in close proximity to an adversary by virtue of its stealthy elements provides an extension to the host ship's organic sensor capability. SSGN can deliver systems of this nature in-theater and synergistically operate with them. The SSGN with PLUSNet-like system payload has the potential to provide:

- Simultaneously coverage of several geographically dispersed areas during a single deployment. Effectively provide the persistent joint ISR necessary to deny adversaries a sanctuary in the littoral area.
- Reduced vulnerability to current anti-access threats such as mines and quiet diesel-electric submarines. Better ability to penetrate denied areas to help ensure joint force access. Permits less vulnerable posture of host SSGN serving as forward command center.
- Significant complications for an adversary's planning and response.
- Increase in the overall payload modularity of the submarine fleet.

- Restore a favorable ASW capability gap that adversaries may not have the money to counter.

(U) The preliminary integration study conducted by Electric Boat indicated that two hypothetical PLUSNet cells would occupy 5 SSGN missile tubes. This configuration will leave 17 SSGN missile tubes available for other payloads such as 119 Tomahawk missiles. The Universal Launch and Recovery Module concept provides sufficient infrastructure to support the launch, stowage and recovery of the mobile elements of the PLUSNet system. Vehicle specific cradles for the baseline URLM will be required. Although the ULRM is applicable to the varied UUVs being considered, recovery of the gliders requires further study. The adaptation of the ULRM for handling and deployment of the fixed array canisters appears feasible but remains an area requiring future development.

(U) As the PLUSNet system evolves beyond the initial design and feasibility testing, early involvement by the ship integration team is recommended to guide the spiral development process. The SSGN provides a readily available test platform with well defined interfaces. Design decision made today with the foresight of SSGN deployment will facilitate the ultimate transition of this new capability to the Fleet.

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9 BIOGRAPHIES

Mr. Marc S. Stewart served as an officer in the United States Navy from 1977 to 1999. He served as a submariner for the first half of his career. Then he served both as a ship repair and maintenance manager and as an acquisition professional within the Engineering Duty Officer community responsible for submarine and Anti-Submarine Warfare system design. Having transitioned to APL-UW in July 1999, Mr. Stewart works on developing systems for collecting and understanding environmental data to enhance decision-making process for the employment of acoustic sensors. Current projects involve directing a major multi-year ONR-funded sea experiment, “PLUSNet,” involving numerous acoustically networked fixed and mobile sensors and coordinating the fleet introduction of glider-AUV technology.

Mr. John R. Pavlos is an Engineering Project Manager with General Dynamics – Electric Boat. His background is in naval architecture and systems engineering of advanced undersea systems. John is Electric Boat’s Technology Area Team leader for off-board vehicles and has contributed to numerous Electric Boat Concept Formulation (CONFORM) studies. He was the team leader for platform integration for the Team 2020 Industry Consortium and subsequently served as the Project Manager for the successful Flexible Payload Module advanced development program. Mr. Pavlos has a BA in Physics and a MS in Ocean Engineering.

Figure 1 (U) Seahorse AUV with Large UUV Passive Array (LUPA) (from ARL/PSU)

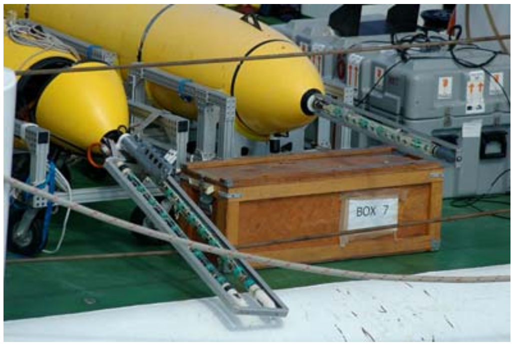


Figure 2 (U) Bluefin-21 AUVs showing single and dual linear nose arrays (above) and array towing assembly model (from Bluefin Robotics, Inc.) (below)

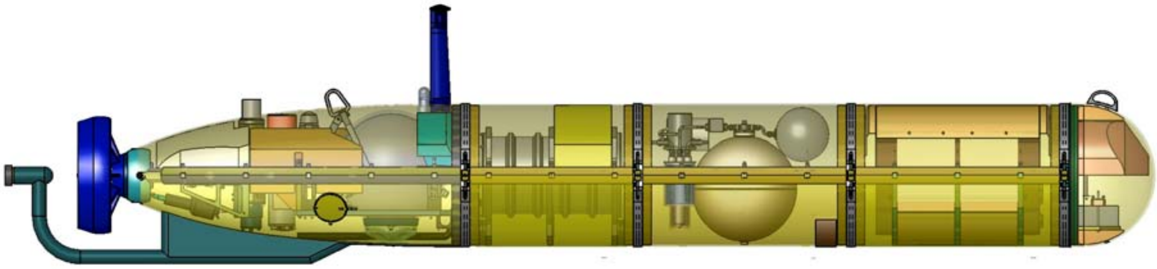


Figure 3 (U) Seaglider AUV during shipboard recovery (from APL-UW)

Figure 4 (U) Slocum AUV with multi-element towed array in storage (from SSC)

Figure 5 (U) XRay AUV full scale hull form (from SIO/MPL)

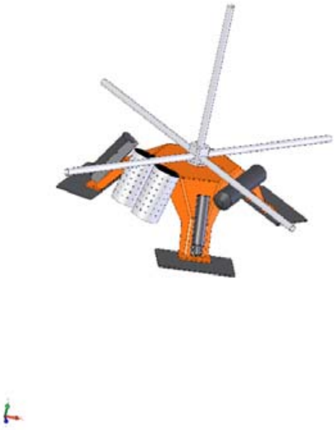


Figure 6 (U) Electric Field Sensor model (from APL-UW)

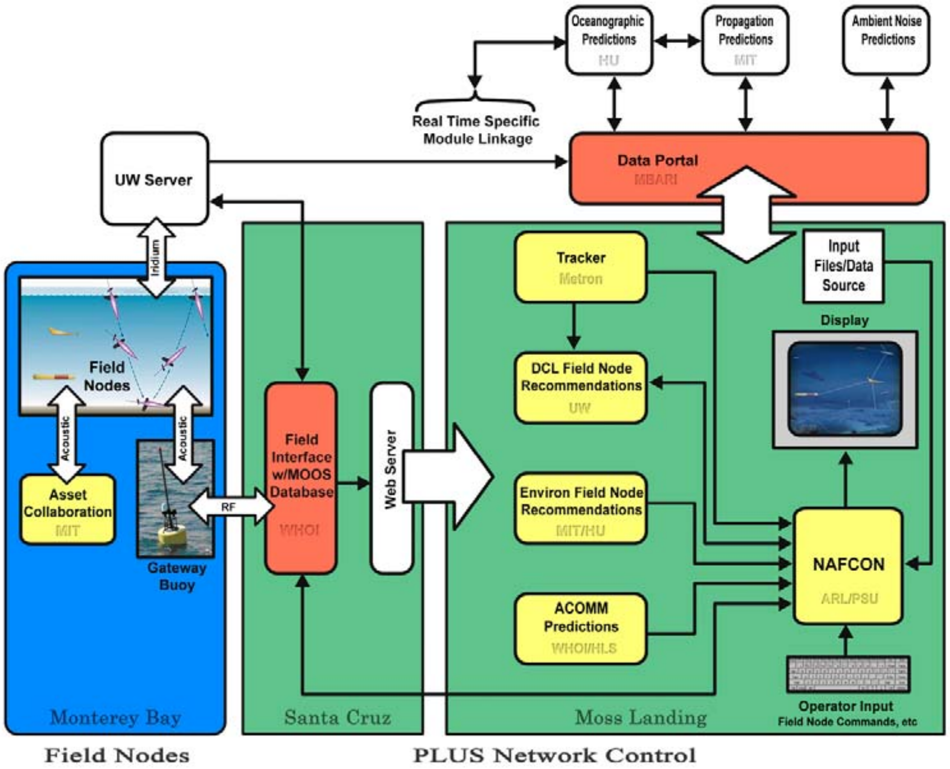


Figure 7 (U) PLUSNet Shore component configuration and connections (from ARL/PSU)

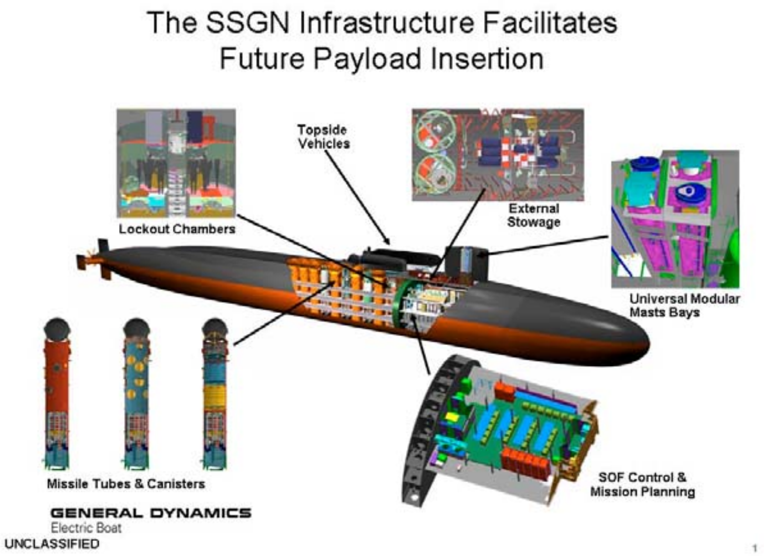


Figure 8 (U) SSGN Ocean Interfaces

Figure 9 (U) SSGN Universal Launch and Recovery Module

Figure 10 (U) Vehicle Launch and Retrieval Sequence

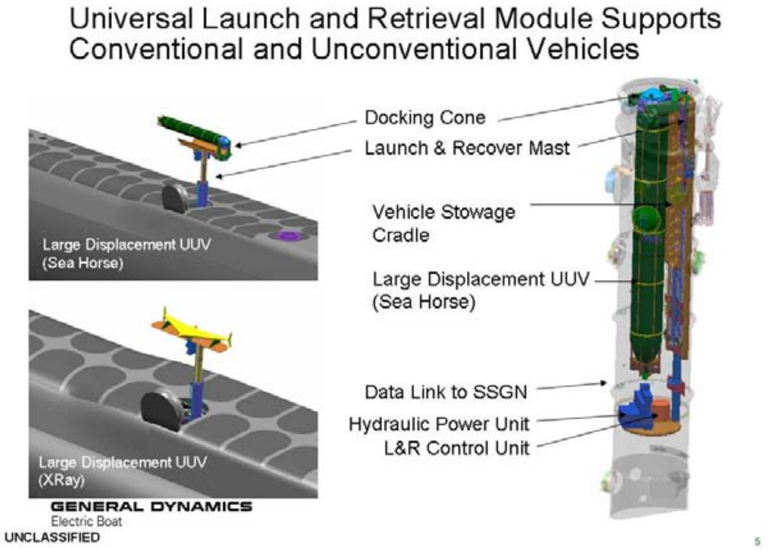
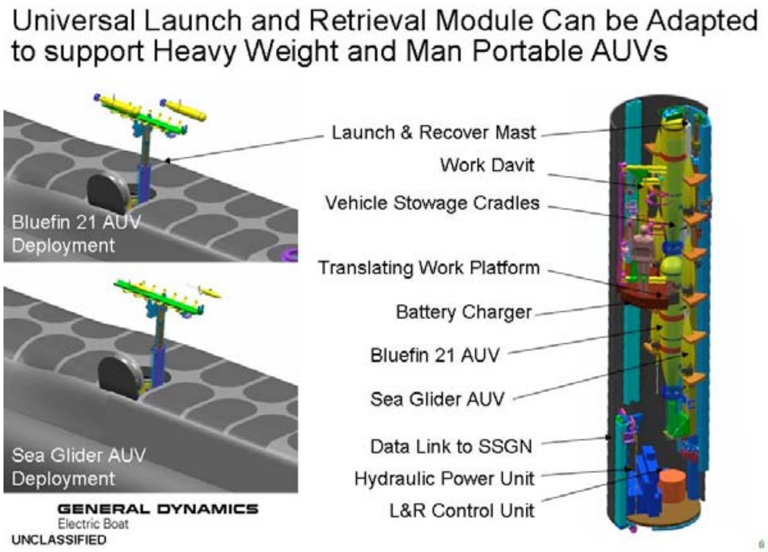
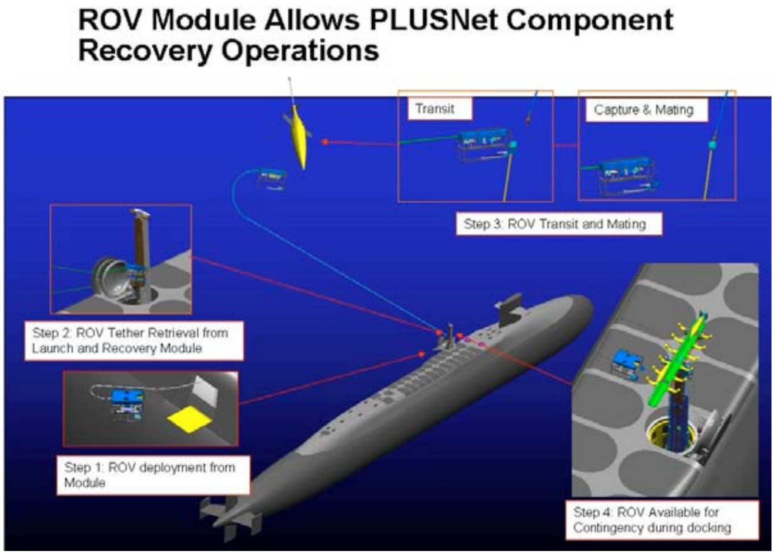

Universal Launch and Retrieval Module Supports Conventional and Unconventional Vehicles

Figure 11 (U) Large Displacement UUV Launch and Retrieval Module



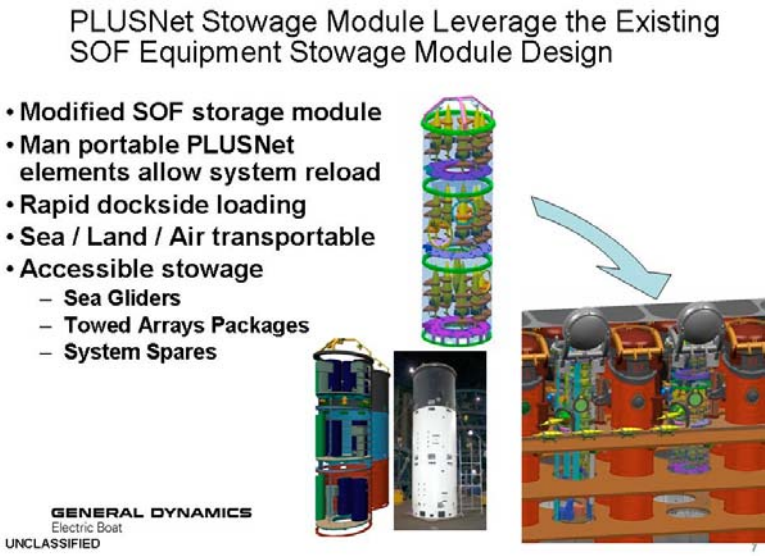
Universal Launch and Retrieval Module Can be Adapted to support Heavy Weight and Man Portable AUVs

Figure 12 (U) Bluefin 21 and Seaglider Launch and Recovery Module



ROV Module Allows PLUSNet Component Recovery Operations

Figure 13 (U) ROV-Assisted Seaglider Recovery Operation



PLUSNet Stowage Module Leverage the Existing SOF Equipment Stowage Module Design

- Modified SOF storage module
- Man portable PLUSNet elements allow system reload
- Rapid dockside loading
- Sea / Land / Air transportable
- Accessible stowage
  - Sea Gliders
  - Towed Arrays Packages
  - System Spares

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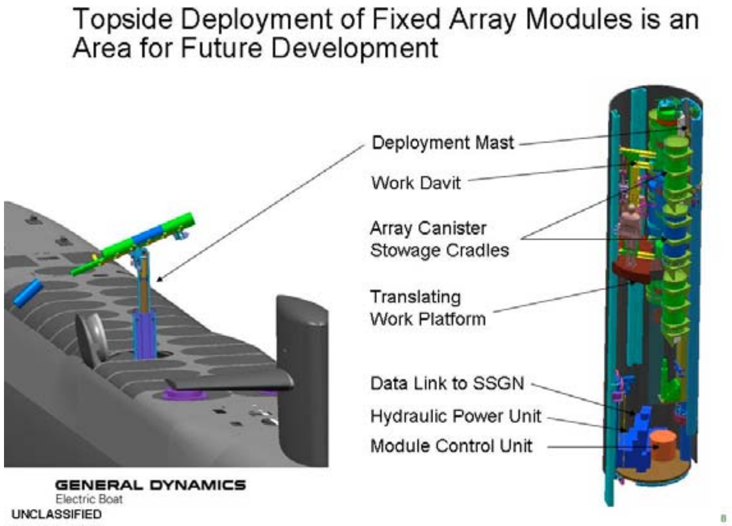
Figure 14 (U) PLUSNet Stowage Module, Logistics Path Between Missile Tubes



Topside Deployment of Fixed Array Modules is an Area for Future Development

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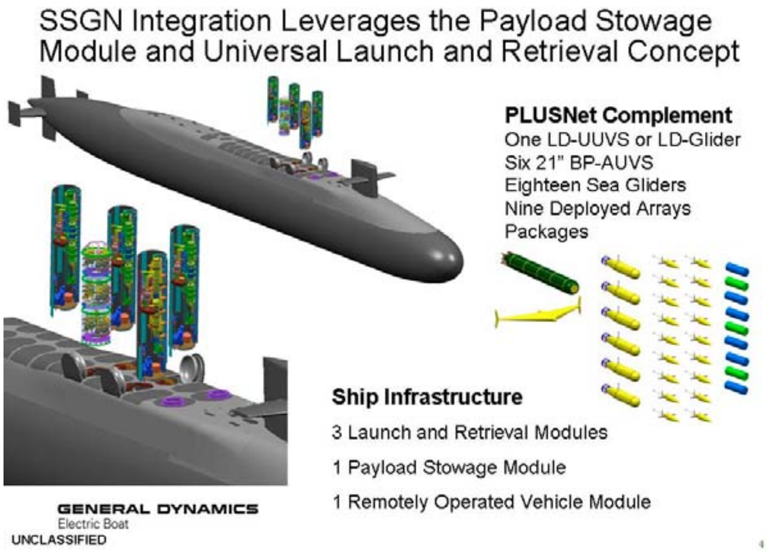
Figure 15 (U) Deployable Array Delivery Module



SSGN Integration Leverages the Payload Stowage Module and Universal Launch and Retrieval Concept

PLUSNet Complement

One LD-UUVS or LD-Glider
Six 21" BP-AUVS
Eighteen Sea Gliders
Nine Deployed Arrays Packages

Ship Infrastructure

3 Launch and Retrieval Modules
1 Payload Stowage Module
1 Remotely Operated Vehicle Module

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Figure 16 (U) Notional SSGN – PLUSNet Load-out