# AUTONOMOUS UNDERSEA SYSTEMS NETWORK (AUSNET) – PROTOCOLS TO SUPPORT AD-HOC AUV COMMUNICATIONS


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## Abstract

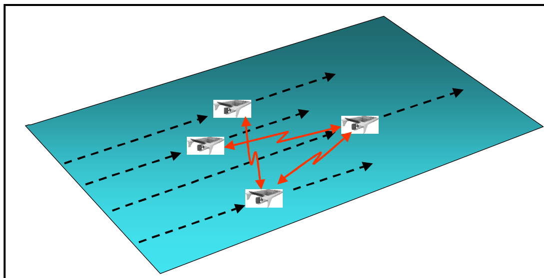
This paper reports progress within the AUSNET (Autonomous Undersea Systems Network) program. AUSNET addresses the need for ad-hoc self forming networks that can operate in the low-bandwidth undersea environment. The AUSNET program has focused on creation of a network capability based on Dynamic Source Routing (DSR), including the Application Programmer's Interface (API) between the network drivers and the autonomous undersea applications using these drivers. The capability has been tested within the Cooperative AUV Development Concept (CADCON) simulation environment, and self forming and adaptive network capabilities have been demonstrated. Additionally, the incorporation of dead-reckoning algorithms into the AUSNET protocol has resulted in a dramatic reduction in the number network routing packets required to support the self-forming network, thus enabling improved performance and releasing bandwidth for content (as opposed to network support) data transmissions. Next steps in this effort will focus on store and forward capabilities. Additional discussion will provide an overview of the planned transition into an operational environment. The final objective of the AUSNET program is to provide a network capability that will enable the AUV community to achieve interoperability both rapidly and cost effectively.


## Background

AUSNET (Autonomous Undersea Systems Network) is an NSF funded STTR Phase 2 program addressing network protocols for undersea communications. The effort is being performed by Technology Systems, Inc. (TSI) of Wiscasset, Maine, and the Autonomous Undersea Systems Institute (AUSI) of Lee, NH. The program is in its second year of Phase 2 execution.

Autonomous undersea systems require communication networks in order to work cooperatively towards common goals. The underwater environment, however, presents profound constraints on communication bandwidth. Furthermore, traditional protocols have the limitation of not being optimized to support a dynamically evolving topology of truly semi-autonomous networked robots. Emerging flexible low bandwidth, energy efficient architectures and protocols will enable more effective networked subsurface robotic capabilities to be possible. The interface between these emerging capabilities and the applications that might use them is an area that is underdeveloped yet critical for optimum network system engineering.

Applications for such an underwater network are limitless. The ability to form acoustic ad-hoc (self-forming, self-maintaining) networks from an assorted collection of platforms, ranging from simple sensors to unmanned autonomous vehicles to manned submersibles, would allow a richly interactive environment for data collection, surveillance, data distribution and collaborative planning and processing.



**Multiple AUVS working cooperatively**

Traditional existing architectures for distributed control of robotic and/or sensor systems have assumed a fixed, high bandwidth environment. This has enabled adaptive communications architectures to be evolved which support powerful distributed applications such as distributed simulations, supercomputer based analysis of distributed databases, and so forth. While current network based distributed computing techniques exist (e.g. CORBA, HLA), they are characterized by high bandwidth requirements. In this regard, these techniques are ill suited to the underwater domain. The environment in which autonomous undersea systems must operate is fundamentally different due to the low bandwidth inherent to undersea communications systems.

*Phase 1*

The AUSNET project focuses on the development of an Application Programmer's Interface (API) coupled to a communications stack tailored to support ad-hoc networks. As part of the Phase I effort, we identified DSR (Dynamic Source Routing) as a potential communications stack protocol. DSR is a draft internet standard that will support ad-hoc networks by enabling the network to be completely self-organizing and self-configuring. The initial AUSNET strategy was for AUSNET to provide an API to an emerging protocol such as DSR.

For a viable AUSNET implementation DSR was an excellent candidate communications stack, however, DSR was not currently fully developed or commercially available. For this reason, the AUSNET approach was further refined to include a simplified DSR implementation tailored to the unique needs of the undersea network environment.

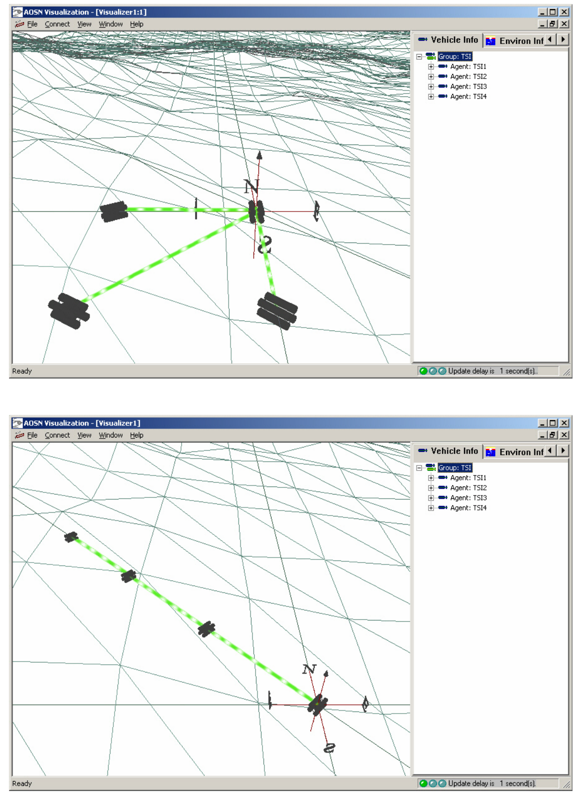
The innovations of AUSNET are:

1) Network level protocols (AUSNET Protocol, or AP) that implement Dynamic Source Routing (DSR) protocols in a manner optimized for smaller groups operating in a low bandwidth environment.
2) An approach that exploits the data present in a mobile ad-hoc network to support the application in new ways.

The problem being addressed breaks down into 3 parallel components:

1) The AUV system and its needs for communication to acquire information necessary to cooperate with other platforms in accomplishing a defined task,
2) The API and its ability to interface with the constraints implied by the limited and unreliable communications of the underwater environment; and
3) The network protocols that support self forming ad-hoc topologies of network nodes.

A demonstration of feasibility was achieved by creating a fleet of simulated AUVs that navigated cooperatively within a simulated undersea environment. The scenario in which the fleet navigates is based upon a search for a "black box" as follows a sea-based aircraft accident. The AUV fleet starts in a cluster, as if just launched from a ship, and then transitions into a line formation to start a search pattern. The start of the exercise (where organized as a cluster) requires that the network autonomously configure itself. Then, when they extend into a line formation, this induces change in the network's topology, requiring new routings to be discovered and utilized.




**CADCON screen shots showing start and end conditions of the Phase I demonstration. Note that the communications path (green dashed line) transitions from a direct link between AUVs, to a multi hop configuration as the fleet formation is changed.**

*Preliminary Findings and Results*

The AUSNET API and underlying protocols performed as expected. Testing included the capability to adjust the simulated undersea bandwidth, and AUSNET was found to perform adequately in a low bandwidth environment. Feasibility testing was accomplished in which 4 AUVs were navigated from one AUV fleet formation to another AUV fleet formation, thus changing the network topology and routing requirements. AUSNET established and then reconfigured routing as designed, thus demonstrating concept feasibility.

The DSR protocols, which are currently being developed by the IETF Mobile Ad Hoc Networks Working (MANET) Group, are robust and suitable for the lower layers of the proposed application, but support a degree of scalability that AUVs will never require. This scalability has a cost (in bandwidth and compute requirements) that can be substantially reduced by streamlining DSR concepts and creating a tailored implementation suitable for use undersea (or anywhere low bandwidth is a constraint). The variations introduced to meet AUSNET requirements have reduced the packet size (primarily by reducing the header size), created a new protocol (AP, or AUSNET Protocol) and set the stage for more advanced

Phase 2 variations that will exploit the unique characteristics of the AUV environment.

## Current Project Status & Findings

AUSNET has modified the DSR (Dynamic Source Routing) protocol by optimizing it for undersea operation. AUSNET and DSR are based upon each network node also being capable of acting as a network router. Thus, all network infrastructure is inherent in the network nodes, which eliminates the need for additional routers, gateways, and similar systems, and the configuration overhead associated with them. The resultant capability grows and collapses as nodes join or leave, is self healing, and supports entirely ad-hoc topologies. With this added capability increased overheads to support routing are required, which can considerably increase the bandwidth requirements for operational use.

*AUSNET Testing*

A key element of the Phase II effort is that a means to fully test the ad-hoc reconfiguration of an AUSNET network is required. Recent efforts focused on the creation of a CADCON based test capability that will enable repeatable tests that exercise specific facets of the discovery, routing, and maintenance functions. This was achieved by creation of scenarios that initialize a fleet of AUVSims to known locations and in known navigational states. Scenarios are loaded and then the overall fleet simulation is run to exercise the AUSNET capability.

An additional mechanism was implemented that enables the overall network activity to be captured for analysis. Thus, network behavior can be confirmed in detail, and proof of AUSNET functionality can be established through examination of empirical results. A 'debug' channel was added to the CADCON communications harness, enabling comprehensive logging of communications activity.

Specific AUSNET functions that have been empirically tested and the results documented include:

- New route request – resolution by discovery from a dead start (cluster example): It has been tested and shown that communications are established between all AUVSims when started within a small area that allows communication links to be established.

- Route failure and new route discovery from working topology (Cluster to Line): It has been tested and shown that communications are interrupted and reestablished when the cluster of AUVSims move into a line formation. The line has then moved in a radial search pattern, which proves that all AUVSims are somewhere within the communications hierarchy and able to receive commands from the master AUV.

- Route failure from node removal – non recoverable: It has been tested and shown that when nodes navigate beyond communications range from any node, route failure is detected appropriately.

- Route failure from node removal – recoverable with no new nodes: This has been tested successfully within the cluster to line mode, wherein established routes fail and new routes are established within an established set of nodes.

- Route failure from node removal – recoverable with a new node: This has been tested successfully within the cluster to line mode, wherein established routes fail and new routes are established within an increasing number of nodes.

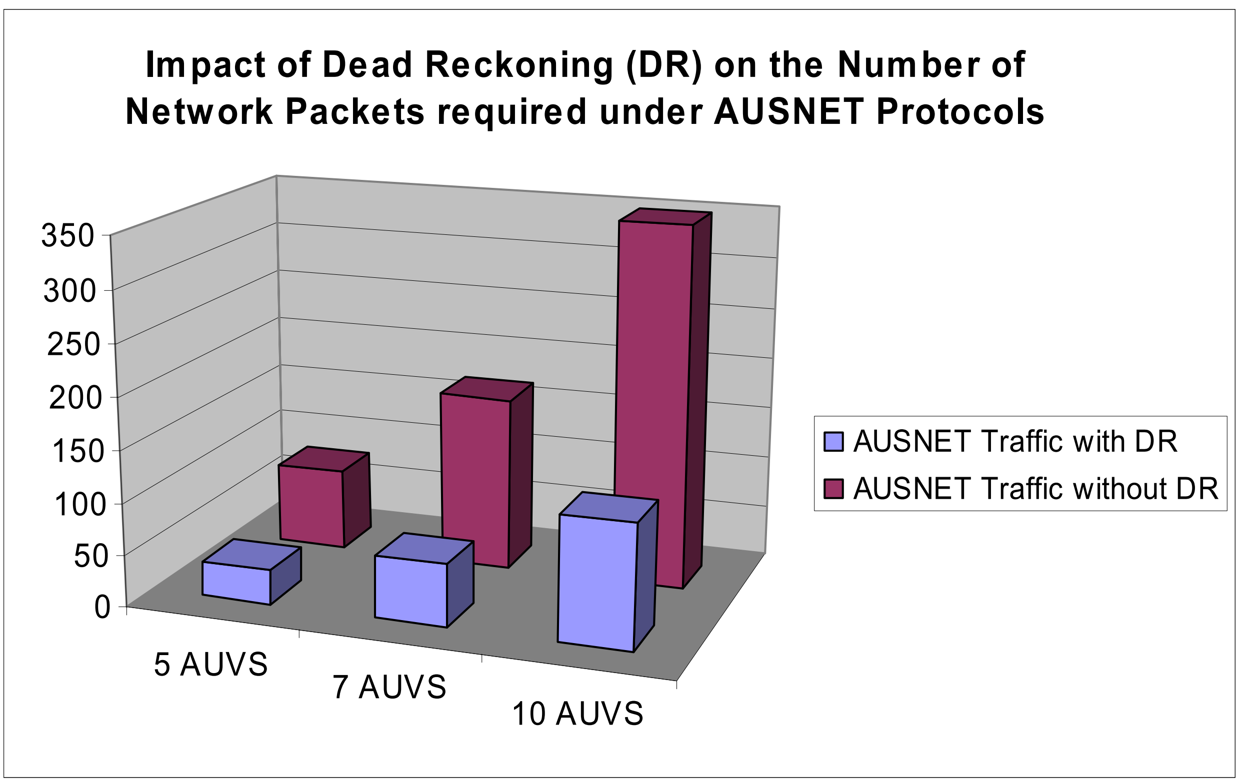
*Dead Reckoning Ad-hoc Network Topology*

A significant issue with AUSNET (and any actively reconfigurable network) is the overhead incurred in identifying and maintaining network topology. This overhead can be significant, and the identification and creation of methods to reduce this overhead has been a goal of the AUSNET project.

AUSNET has been able to significantly reduce these overheads by exploiting the fact that multiple AUVs generally work cooperatively according to well defined conventions, following predictable routes and so forth. Nodes in a traditional DSR implementation constantly update their model of the network topology using the DSR protocols. AUSNET models network topology by using Dead-Reckoning (DR) techniques to extrapolate node positions based upon the AUV fleet behaviors as defined by standardized conventions (while retaining the ability to fall back upon traditional DSR protocols if required). As shown in the figure below, this approach dramatically reduces the overheads associated with a DSR based implementation. The data was acquired through empirical testing within AUSI's simulation environment, CADCON.

The net result is that AUSNET enables one to gain all the benefits of ad-hoc network technologies, including the elimination of infrastructure, with full scalability and self-forming / self-healing capability, ***while retaining nearly all the bandwidth*** of a traditional fixed network using TCP or UDP protocols. The AUSNET capability is thus an enabling technology for emerging undersea networks such as the Autonomous Oceanographic Sampling Networks (AOSNs) and similar AUV fleet capabilities.

*Transition to Live Operations and Testing*



AUSI is the world leader in Solar AUV (SAUV) technologies, and is currently about to launch 2 second generation SAUVs under contract to ONR. These are being built by Falmouth Scientific, Inc. (FSI), with core software provided by AUSI, and top level operational software by TSI. These SAUVs will have acoustic modems that can utilize AUSNET protocols (which are simply used to package the serial packets used for communications).

SAUVs are unique because they are capable of long term, sustained operations that do not require the expense of support ships. Thus, long term AUV fleet operations are uniquely enabled by SAUVs, not only due to their long term capabilities, but also because the economics of their usage are fundamentally different than that for traditional AUVS that are limited by battery life.

Clearly, the integration of AUSNET capability into the SAUV system is a logical next step. As part of the AUSNET Phase 2 effort, we will integrate AUSNET protocols into these SAUVs. The primary objective of this effort will be to quantify the added value of AUSNET over traditional undersea communications protocols. This has been preliminarily done within simulation, but needs to be verified through at-sea testing. Additionally, the AUSNET protocols provide the basic frame-work for an intelligent store-and-forward capability that exploits the predictable behaviors of AUV fleets over time. This capability will be further explored during at sea testing.

## Summary

AUSNET has been demonstrated to support undersea ad-hoc networking with increased performance achieved through the exploitation of AUV fleet behaviors, specifically the dead-reckoning of node locations. AUSNET has modified the DSR (Dynamic Source Routing) protocol by optimizing it for undersea operation. Each network node is capable of acting as a network router, thus all network infrastructure is inherent in the AUV fleet itself. The resultant capability grows and collapses as nodes join or leave, is self healing, and supports entirely ad-hoc topologies. Exploitation of fleet behaviors has significantly reduced the increased overheads normally required, and should enable AUSNET capability to meet operational requirements. Testing within simulation is complete, and next steps are focused on initial at-sea testing, and store/forward capability development.