AUTONOMOUS UNDERSEA SYSTEMS NETWORK (AUSNET)
Development Status Update

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Abstract

The standardization of network protocols and interfaces promises to significantly enhance the capabilities of Autonomous Undersea Vehicles (AUVs) as they become more commonplace and are deployed in teams. A range of AUV systems is currently emerging, each with different strengths and attributes, and the ability for these to be cooperatively deployed requires the establishment of standard interoperability protocols. This paper provides an overview of an ongoing effort called AUSNET (Autonomous Undersea Systems Network). AUSNET addresses the requirements imposed by the need for ad-hoc self forming networks that can operate in the low-bandwidth undersea environment. The AUSNET effort is focused on the creation of a TCP/UDP-like network capability, which is based on Dynamic Source Routing (DSR). The effort includes the implementation of an Application Programmer's Interface (API) between the network drivers and the autonomous undersea applications using those drivers. The goal is to create a robust and efficient set of standard protocols and specifications that can be adopted by the AUV community to enable rapidly achievable and cost effective interoperability.

AUSNET Overview

The AUSNET effort is a Small Business Technology Transfer and Research (STTR) project funded by the National Science Foundation (NSF). The Phase I program was completed in 2001 and resulted in the development of a preliminary design that met critical requirements not addressed by existing network systems [Nitzel, et. al, 2001]. The AUSNET design builds upon emerging work within the Internet community (DSR) to provide a self-configuring ad-hoc network suitable for the low-bandwidth undersea environment. Phase I demonstrated feasibility through creation of a simulation based implementation.

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 Phase II technical objectives are to:

1) Fully develop and implement the lower level AUSNET Protocol (AP) capability.

2) Fully develop and implement the AUSNET API design.
3) Test, refine, and demonstrate capability in the CADCON environment.
4) Transition the AUSNET capability into a live Solar AUV.
5) Enable Phase III success through creation of a robust, complete, tested AUSNET implementation ready for commercial application.

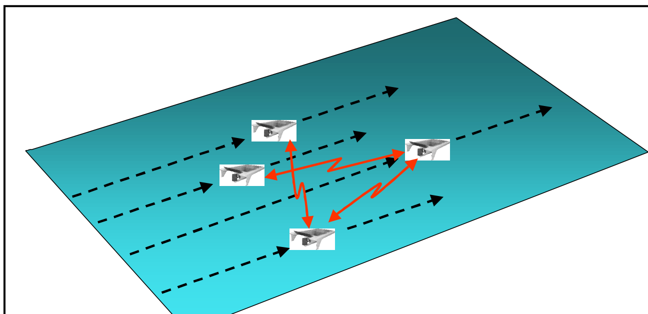
The Phase II goals are to create a commercially viable capability that will enhance autonomous undersea systems capabilities, improve fundamental network science, and enable simulated and live autonomous undersea vehicles to effectively communicate in the context of cooperatively performing various tasks.

This effort is being performed by a combined STTR team, lead by TSI and assisted by the Autonomous Undersea Systems Institute (AUSI). TSI is developing and implementing the low level software (e.g. DSR derived software), API level software required for AUSNET, and application level software (beyond the API). All application requirements of the system have been determined by AUSI, and AUSI provided the multi agent simulation harness: CADCON [Chappell and Komerska 2001, Chappell et. al. 1999].

Background

Distributed autonomous systems require communication networks in order for the participants to work cooperatively towards common goals. The underwater environment, however, presents profound constraints on communication connectivity and 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 the realization of more effective networked subsurface robotic capabilities. 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 through unmanned autonomous vehicles to manned submersibles and surface support vessels), would provide a richly interactive environment for data collection, surveillance, data distribution and collaborative planning and processing. A hypothetical group survey with networking is diagrammed in figure 1.


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 the development of adaptive communications architectures, 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 needing continuous high bandwidth connectivity. In this regard, such 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 and high probability of command path failure inherent in undersea communications systems.

Dynamic Source Routing

An emerging architecture and protocol for distributed ad-hoc networks is known as Dynamic Source Routing (DSR). The development of DSR is a large scale effort, supported by the Internet Engineering Task Force, Mobile Ad-hoc Networks (IETF MANET) Working Group. Development has been underway since 1997, and the product is currently reflected in the current Internet-Draft specification that is 80 pages long (http://www.ietf.org/internet-drafts/draft-ietf-manet-dsr-07.txt). The following is copied from the abstract of the most recent DSR Internet Draft:

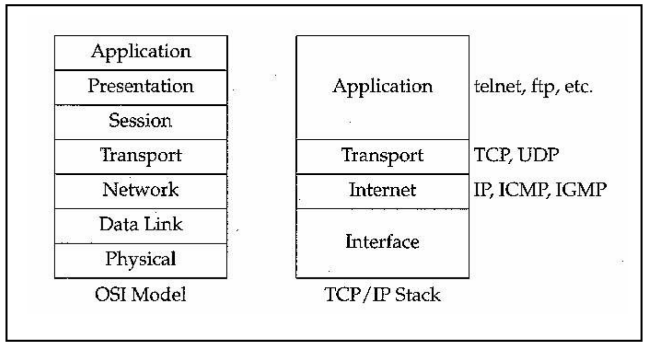
> *"The Dynamic Source Routing protocol (DSR) is a simple and efficient routing protocol designed specifically for use in multi-hop wireless ad hoc networks of mobile nodes. DSR allows the network to be completely self-organizing and self-configuring, without the need for any existing network infrastructure or administration. The protocol is composed of the two main mechanisms of "Route Discovery" and "Route Maintenance", which work together to allow nodes to discover and maintain source routes to arbitrary destinations in the ad hoc network. The use of source routing allows packet routing to be trivially loop-free, avoids the need for up-to-date routing information in the intermediate nodes through which packets are forwarded, and allows nodes forwarding or overhearing packets to cache the routing information in them for their own future use. All aspects of the protocol operate entirely on-demand, allowing the routing packet overhead of DSR to scale automatically to only that needed to react to changes in the routes currently in use. This document specifies the operation of the DSR protocol for routing unicast IP packets in multi-hop wireless ad hoc networks."*

An example commonly used to represent a potential large scale ad-hoc network is a wireless telephone system located in rural mainland China, where no supporting infrastructure exists. A system such as this would have an extremely large number of users and a constantly changing topology. The phones themselves would provide the network infrastructure, daisy chaining a traffic dynamically across the free-form network. Realistically, a long distance phone call (>1000 miles) would probably not be very feasible. However, the DSR protocols being developed aim to provide robust, scalable, on-demand functionality in a widespread, large population environment (not as large as China, but potentially across a large military battlespace or FEMA type emergency operations area).

For the foreseeable near-term (10-15 years), the cooperative AUV market will never require the ability to support vast numbers of potential users on a scale similar to that which DSR will support. Likewise, cooperating AUVs change their topology in somewhat predictable and structured ways, which is quite different from the assured randomness of the telephone example. This observation is a critical component that differentiates AUSNET requirements from those of DSR. All the same, there is great opportunity to take advantage of the emerging DSR protocols, and to exploit the work performed to date in creating a variation tailored to meet the AUV community's needs.

The following discussion is provided to clarify where DSR, AUSNET low-level functionality, and AUSNET API functionality reside within the OSI 7-layer or TCP/IP Stack (See Figure 2).

1 AUSNET API exists at the application layer,
2 AUSNET low level functions range from the application layer down to the network or internet layer, and
3 DSR is focused at the network or internet layers.



Summary of Phase I Work

DSR is not currently fully developed or commercially available. Phase I effort was, therefore, directed at the generation of a prototype implementation of DSR for AUSNET. During this time, we incorporated some significant deviations from the DSR specification to address specific constraints of submerged communication:

1 AUSNET uses much shorter headers, and is designed to support a limited number of users (<64 per subnet), which we term AUSNET Protocol (AP), as opposed to Internet Protocol (IP).
2 AUSNET's routing and discovery mechanisms are similar to DSR's, but have the potential to be dramatically simplified since their potential scale is much smaller.
3 AUSNET will have an AUV oriented layer that will exploit unique AUV attributes such as low rates of transit and predictable navigation paths.

A Phase I set of high level AUSNET API functionality was developed to demonstrate concept feasibility, including sending a message, receiving a message, and network configuration (e.g. address assignment). Low-level AUSNET network functionality was also identified and implemented, including route discovery, route maintenance and sending data. The Phase I effort addressed a subset of the functions required by networked AUVs: navigation as a group.

The Phase I scenario is based upon the first step that an AUV fleet would perform is a search or survey application. More specifically, a fleet of AUVs will typically be brought to an area by a ship and then launched to perform specific data collection tasks. For example, the search for a black box (as occurs when a commercial airliner crashes in the ocean) would typically follow this pattern. Once launched, the AUV fleet would find itself in a cluster (see figure 3), with no particular knowledge of how many AUVs were in the fleet, or where they were physically located relative to each other. This sets the stage for the initial testing and demonstration of the Route Discovery mechanisms.

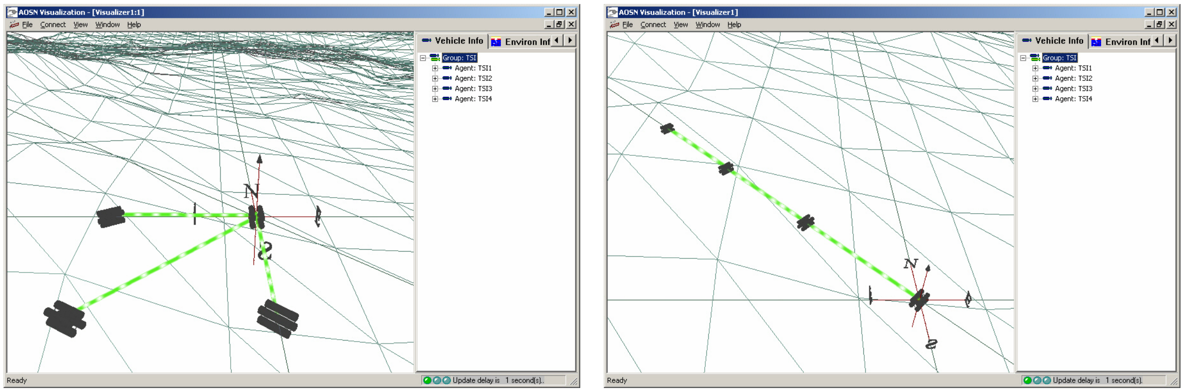


Figure 3. CADCON screen shots showing start and end conditions of the Phase I demonstration. Note that the communications path (green dashed line) transitions from a direct link (lead AUV to subordinates) to a multi hop configuration as the fleet formation is changed.

Phase I testing and demonstration was performed using the CADCON server (which is Internet based and managed by AUSI), with AUV simulators and visualization tools being run at both TSI's and AUSI's offices. This Phase I capability explicitly demonstrated the core technical capabilities and feasibility of AUSNET, and provided an 'early version' demonstration of the protocols and API that AUSNET will embody. To support Phase I AUSNET testing, AUSI modified the CADCON server to be able to provide a selection of possible communication media for its clients. For AUSNET testing, the principle communication model we implemented was a simplified acoustic channel (see Nitzel, et. al., 2001).

By performing Alpha testing within Phase I we have moved the R&D process significantly forward, thus enabling identification of issues to be examined in Phase II early in the overall process. We have also used Phase I to reduce technical risk and thus enable an accurate and realistic Phase II work plan and budget to be developed.

Phase II Work

For Phase II, we have changed the academic flavor of the AUSNET effort to a more commercial orientation. The code has been reorganized and reimplemented in the form of a separate library of functions. When completed, this will render the AUSNET functionality suitable for other runtime contexts besides that of a CADCON client. This is an important step in process of turning AUSNET into a product that can be linked with other software.

Additionally, the AUVSim and CADCON system was modified to allow for simultaneous use of various communication media. This opens the door to routing agent to agent communications based on which communication medium is functioning, or more effective, or less error prone.

AUSNET Test Plan

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. Current efforts are focused on the creation of a test capability that will enable repeatable tests that exercise specific facets of the discovery, routing, and maintenance functions. This will be achieved by creation of scenarios that will initialize a fleet of AUVSims to known locations and in known navigational states. Scenarios will be loaded and then the overall fleet simulation will be run to exercise the AUSNET capability.

An additional mechanism is being implemented that will enable the overall network activity to captured for analysis. Thus, network behavior can be confirmed in detail, and proof of AUSNET functionality can be established through examination of empirical results. To achieve this, a 'debug' channel is being added to the CADCON communications harness to enable comprehensive logging of communications activity.

Specific AUSNET functions to be empirically tested and documented include:

- New route request – resolution by discovery from a dead start (cluster example)
- Route failure and new route discovery from working topology (Cluster to Line)
- Route failure from node removal – non recoverable
- Route failure from node removal – recoverable with no new nodes
- Route failure from node removal – recoverable with a new node
- Shorter Route detection
- New route request – resolution by examination of known paths discovery

AUSNET transition to live operations

Once we have empirically demonstrated AUSNET functionality in the simulated environment, we will transition the capability into a controlled live environment. This will be accomplished by adding real (not simulated) acoustic modems to two AUVSims and enabling them to communicate through a pool of other body of water. It should be noted that the AUVSims will still be connected to CADCON via the CADCON network, and that the debug communications channel will be still be present to enable capture of all AUSNET events. However, all actual AUSNET network traffic between the two modem enabled AUVSims will be directed through the real world acoustic medium. This will empirically demonstrate that AUSNET functionality should be fully capable outside of the CADCON environment and set the stage for the final transition of AUSNET into live, at sea operations.

Summary

Phase I has also resulted in the demonstration of the Cooperative AUV Development Concept (CADCON) testbed that will enable Phase II and Phase III AUSNET development to proceed efficiently and cost-effectively. Phase II is proceeding toward achieveing a full AUSNET implementation that will be ready for transition to at sea operations by the summer of 2003.

References

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