AUTONOMOUS UNDERSEA SYSTEMS NETWORK (AUSNET)

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Abstract

The standardization of network protocols and interfaces will significantly enhance the capabilities of Autonomous Undersea Vehicles (AUVs) as they become more commonplace. A range of AUV systems are emerging, each with different strengths and attributes, and the ability for these to be cooperatively deployed requires that standard interoperability protocols be established. This paper provides an overview of an 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. AUSNET is focusing on the 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 goal is to create a robust and efficient set of standard protocols and specifications that can be adopted by the UAV community to enable interoperability to be achieved rapidly and cost effectively.

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 recently completed and resulted in development of a preliminary design that meets a critical requirement not addressed by existing network systems. 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, and set the stage for Phase II development.

Background

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. A hypothetical group survey with networking is diagrammed in figure 1.

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.

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 IETF MANET Working Group (Internet Engineering Task Force, Mobile Ad-hoc Networks Working Group). Development has been underway since 1997, and the product is currently reflected in a Internet-Draft specification that is 60 pages long (http://www.ietf.org/internet-drafts/draft-ietf-manet-dsr-05.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.

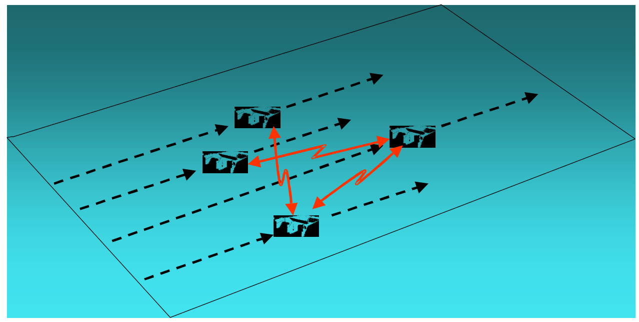


Figure 1. Multiple AUVS working cooperatively

The protocol is composed of the two 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 mainland China. A system such as this would have no supporting infrastructure, an extremely large number of users, and a constantly changing topology. 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 Chinese 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).

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

Summary of Phase I Work

For a viable AUSNET implementation, DSR is an excellent candidate communications stack, however, DSR is 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 AUSNET approach has resulted in development of aderivative implementation, which incorporates some significant deviations from the current draft DSR specification, including:

- 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).
- 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.
- AUSNET will have an AUV oriented layer that will exploit unique AUV attributes such as low rates of transit and predictable navigation paths.

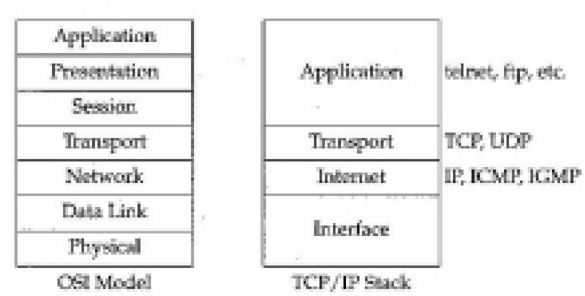


Figure 2. OSI TCP/IP Model

A Phase I set of high level AUSNET API functions were developed to demonstrate concept feasibility, including initialize, update, and receive. Low-level AUSNET network functions were also identified and implemented, including Route Request, Route Reply, and Data Send. A demonstration plan was developed and implemented that exercised these Phase I capabilities.

The Phase I effort has addressed a subset of the functions required by networked Autonomous Undersea Vehicles (AUVs): navigation as a group. This paper discusses the development of an API specification tailored to the needs of the navigation requirement, including testing of it using an existing AUV simulation testbed, which has enabled Phase 1 exploration of conceptual capabilities without the expense (in time and dollars) of doing so in the field.

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.

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].

To support AUSNET testing, AUSI modified the CADCON server in the following manner. Previously, all agent to agent communications rode on a single simulated medium/channel, were perfect (no losses), and nearly instantaneous regardless of the length of the communication and the distance between the sender and the receiver. To effect more realism and, thus, exercise the AUSNET machinery, the server's agent to agent communications code was reworked to provide a set of parameters for each communication. These parameters allow us to now enrich the simulated agent to agent communications with:

- Eight different types of communication medium. This opens the door to routing agent to agent communications through different models based on their type: acoustic, RF, direct connection, laser, etc. For AUSNET work, we implemented only the acoustic channel model.

- Up to 256 channels for each communication medium type. This provides the means to easily separate different varieties of communications on a medium type. In this case, we put AUSNET communications on one acoustic channel, and higher level agent to agent communcations on another acoustic channel.

- A propagation factor for each communication. This value relates to how strong the communication was broadcast and, therefore, how far it may be expected to propagate. The server uses this value to determine the maximum distance the communication can travel from the sender.

- A byte count to specify the size of the communication and a bit rate to specify how fast the communication was transmitted. These are used by the server to compute one part of the propagation delay that is added to each communication.

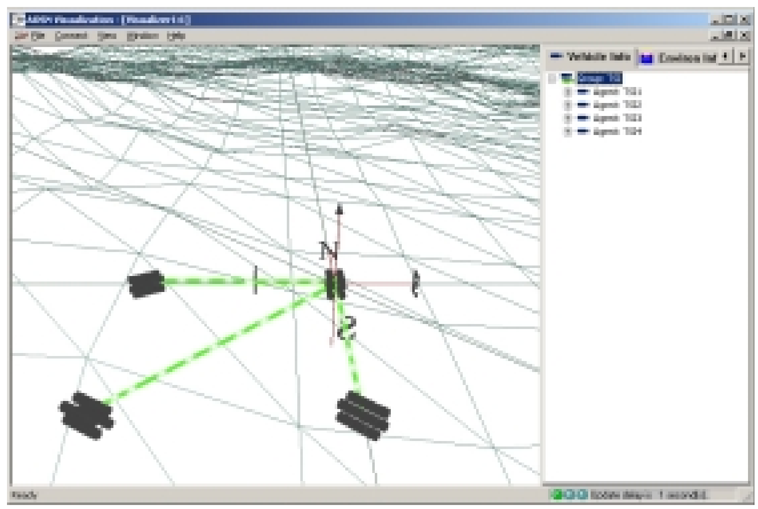
- Finally, a speed of sound parameter was added to the suite of server environment models, which allows it to add another delaying factor to the acoustic agent to agent communications.

All testing of AUSNET capability has been performed jointly.

<u>Phase I Alpha Testing & Demonstration</u>

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 demonstrates the core technical capabilities and feasibility of AUSNET, and provides an 'early version' demonstration of the protocols and API that AUSNET will embody.

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.



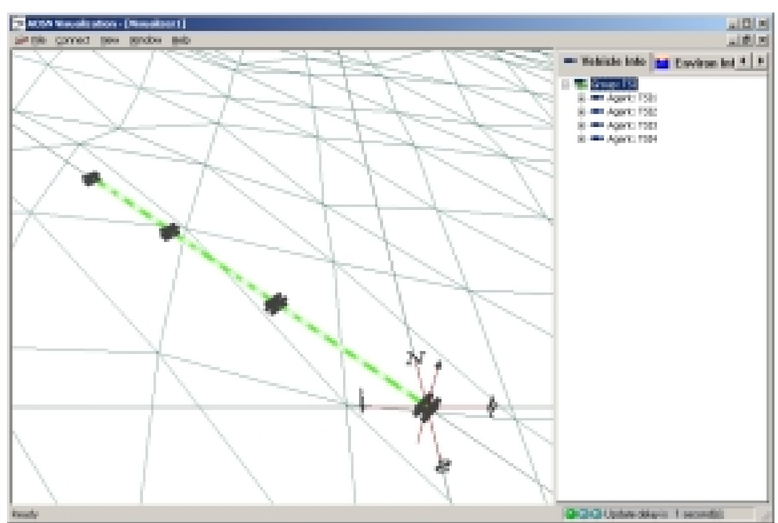


Figure 3. CADCON screen shots showing start and end conditions of the Phase I demonstration. Note that the communications path (green dashed line) transitions from a direct link (lead AUV to subordinates) to a multi hop configuration as the fleet formation is changed.

The start of the exercise (where they organize themselves as a cluster) requires that the network autonomously configure itself. This is implemented by a process wherein when an AUV "wakes up" (e.g. at launch), it sends out a broadcast request (e.g. UDP) to see what other nodes are on the system. If there is no response within a predetermined time limit (currently 20 seconds, but should be determined based upon link speed & quality), it nominates itself as the fleet leader. Subsequent AUVs making the same inquiry will get a response from the leader and then proceed to operate per the leader's instructions. The leader then creates commands for each AUV to achieve the fleet objective.

At the AP level, each AUV communicates with the leader. When in the cluster formation, the leader and fleet AUVS are all within immediate proximity, and thus achieve direct point-to-point connectivity. Once they extend into a line formation, this induces change in the network's topology, requiring new routings to be discovered and utilized.

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.

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 I has set the stage for Phase II by not only proving concept feasibility, but by also creating a robust and appropriate environment for future AUSNET development, testing, and commercial support.

References

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