ADVANCEMENTS WITHIN THE AUSNET™ (AUTONOMOUS UNDERSEA SYSTEMS NETWORK) PROTOCOL

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Abstract

The Undersea Networking environment presents many challenges, such as limited network throughput and extreme latency. It is further hampered by the challenges faced with all Mobile Ad-Hoc Networks, with regard to rapidly changing network topology, Ad-Hoc routing overhead, and dynamic network size. AUSNet (Autonomous Undersea Systems Network) is an NSF funded STTR Phase 2 program (with support from ONR) to addresses these issues. The development effort has been undertaken by Technology Systems, Inc. (TSI) of Wiscasset, Maine and the Autonomous Undersea Systems Institute (AUSI) of Lee, New Hampshire. The AUSNet system has focused on the creation of a multifaceted networking capability based on a specialized implementation of the Dynamic Source Routing (DSR) Protocol fused with an innovative Prediction Based Routing (PBR) Protocol based on the principle of Dead Reckoning. This paper reports advancements within the AUSNet program, chiefly the alterations to the DSR Protocol, the redesign of the PBR Protocol, and the ongoing in water testing and integration efforts.

Background

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 hardware and the autonomous undersea applications using the hardware. A subset of the DSR protocols was identified as appropriate for AUSNET Phase II implementation. For AUSNET, we 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 overhead to support routing is required, which can considerably increase the bandwidth requirements for operational use. 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's PBR system 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). These capabilities are combined to form a multi-platform Application Programmer's Interface (API) to allow the use of the AUSNet Protocol on an exceptionally wide range of deployable autonomous platforms. The AUSNet program has transitioned from small scale testing within the Cooperative AUV Development Concept (CADCON) simulation environment to a Technology Systems Inc developed specialized simulation environment, and to multiple real world testing scenarios. Further, integration of the AUSNet protocol has occurred on multiple autonomous systems. Technology Systems is currently working with AUSI, and the Naval Undersea Warfare Center (NUWC), in Newport, Rhode Island, to complete integration efforts on the Solar AUV and the MARV AUV platforms respectively.

Advancements

The AUSNet STTR program has undergone great advancement within the preceding year. Integration into multiple AUV systems and functional in water testing have been accomplished. Significant improvements to both routing mechanisms, both DSR and PBR, have been made. And a newly devised modular simulator, the TSI Mobile Ad-Hoc Undersea Network Simulator, has been created to ensure optimization and provide empirical data.

AUSNet has been integrated into the communications systems of two AUV models, the Solar AUV (SAUV)[1], and the Mid-sized Autonomous

[1] J. Jalbert, et al., "Solar-Powered Autonomous Underwater Vehicle Development", in Proceedings of the 13th International Symposium on Unmanned Untethered Submersible Technology (UUST03), Durham, NH, Aug. 2003.

Research Vehicle (MARV).[2] The SAUV is produced by Falmouth Scientific and was developed by TSI, AUSI and Falmouth Scientific. The MARV was designed by the Naval Undersea Warfare Center, Newport. Both of these Vehicles utilize AUSNet to communicate location and sensor data in the Common Control Language Version 2 (CCL2)[3] back to the control laptop where the information is displayed with in the AutonomouS Monitor And Control (ASMAC) display tool.[4] This unique combination of technology enables multiple AUVs to be controlled and monitored from one computer.

The concept of Prediction Based Routing has been greatly advanced such that any system capable of providing the AUSNet library with position and velocity information via the API is capable of utilizing this option to make advanced routing decisions based on the knowledge of the movement of the fleet of systems in the water. The real world usefulness of such information is further expanded by the use of several facets of the revised Common Control Language (CCL2) that are designed to allow for a maximum amount of specialized information at a minimum cost of bandwidth.

Routing Improvements

The Dynamic Source Routing component of AUSNet has been reevaluated to ensure its use of the beneficial components of the IETF DSR Standard, particularly the route caching mechanisms have been improved to use the Link-MaxLife option of the standard.[5] Link-MaxLife is a system of attempting to reduce the usage of stale, no longer functional, routes within a Mobile Ad-hoc Network (MANET). It maintains a table of constants relating to each network node, altering them as routes are broken. This yields a system of knowing how likely a node is to wander based on previous experience. Within a node, a route is given a "Lifetime" based on the relative stability of is end point nodes. This lifetime is increased by a successful use of the link for a data transmission originating from either the considered node, or one promiscuously overheard. The optimization of the Link-MaxLife system for the underwater domain required significant modeling, however it has shown significant improvement within DSR under simulation.

The Prediction Based Routing component of the AUSNet system has undergone extensive redesign. The initial concept was for all AUVs to be informed prior to deployment of all other AUVs' operational plans. While this plan was optimal with regard to the bandwidth required for operations, it lacked adaptability for mission alterations. As many AUV platforms

[2] T. Fulton "Simulation and In-water Testing of the Mid-Sized Autonomous Research Vehicle (MARV)", in Proceedings of Unmanned Maritime Vehicle (UMV) Test & Evaluation Conference, Keyport WA, June 2005

[3] Duarte, C. et al., "A Common Control Language To Support Multiple Cooperating AUVs", To Be Presented with the Proceedings of the 14th International Symposium on Unmanned Untethered Submersible Technology (UUST05), Durham, NH, Aug. 2005

[4] Mupparapu, S.S, et al., "Autonomous Monitoring and Control (ASMAC) – An AUV Fleet Controller," presented at IEEE/OES AUV2004: A Workshop on Multiple Autonomous Underwater Vehicle Operations, Sebasco Harbor Resorts, ME, June 2004.

[5] [3] J. Broch, D. Johnson, and D. Maltz, "The Dynamic Source Routing Protocol for Mobile Ad Hoc Networks", IETF Internet Draft, July 2004. [Online] Available: http://www.ietf.org/internet-drafts/draft-ietf-manet-dsr-10.txt

consider on the fly mission changes to be a desirable goal, the PDR component has changed immensely.

The first alteration was to utilize the compressed latitude and longitude structures from the CCLv2. These structures allowed for an accuracy of .1m while using a minimal mount of bandwidth. Following this, accurate means of determining distance and bearing from two latitude and longitude pairs was required. After a significant surveying of the options, the Vincenty Algorithm was chosen due to its ability to scale efficiency, as well as its well know accuracy.[6]

Using these tools, AUSNet models the network of AUVs moving through time. As a message is entered to be sent, the Prediction Based Routing system models the flow of the message through the network, ensuring that all mobile nodes will remain with in transmission range at the time of reception. This works to prevent the race condition where a link between nodes exists at the beginning of the transmission chain, but no longer exists when the message has arrived to use it.

The integration of the modeling system with the optimized data structures left the task of ensuring that the number of required transmissions of this state information was reduced to a minimum. The AUSNet Intelligent Location Update System (AILUS) was devised for this task. Within AILUS, all nodes broadcast their state information at node initialization. While this produces an initial bandwidth overhead, it is the most efficient way to ensure that all nodes receive a needed first update. Further, it provides a reference in time for the node to have achieved a state of awareness of the network. This is important for the second stage of AILUS. When a node receives an initial state update, it must discover if the transmitting node is aware of the receiving nodes place. To achieve this end, AILUS utilizes the route modeling system, but backward, rather than forward, in time. Modeling the path the message had taken; AILUS is able to determine the time the message required to arrive at the receiving node. Since the message is sent as soon as network realization has occurred, if the receiving node's own position broadcast was sent prior to the transmitting node's initialization then a new update needs to be sent. An update packet is created and placed in a buffer. After a set time, a node interrogates the waiting buffer for the required bandwidth to transmit all waiting packets in a directed, routed sense, using the network model, and compares that to the total required bandwidth to send a network wide broadcast. The more efficient solution is chosen, and the packets transferred. When an AUV changes heading or speed, an update packet is formed and broadcasted over the network to all nodes to inform them. The other nodes within the network upon reception of this broadcast use the network model backward in time to determine transmission location of the transmitting node. The course and speed of the modeled node are updated with regard to the new state information at the time of it transmission avoiding the issues where the network model is lagged behind the actual world due to later reception of the information.

[6] T. Vincenty. "Direct and Inverse Solutions of Geodesics on the Ellipsoid With Application of Nested Equations", *Survey Review* XXII, 176, April 1975.

In Water Testing

Significant in water testing of the AUSNet Protocol has been conducted, revealing needs for further work, as well concerns regarding the Benthos acoustic modem hardware. Testing has been conducted in three locations, The Darrin Fresh Water Institute, in Bolton Landing, NY, The Naval Undersea Warfare Center (NUWC) Newport, in Newport RI, and NUWC-Keyport, in Keyport, WA.

AUSNet testing was conducted at the Darrin Fresh Water Institute twice, in June and October 2004. The initial testing on Lake George revealed several issues regarding the AUSNet Protocol that required further refinement. These issues were addressed over the coming months, leading to the October Tests. The October tests demonstrated the in-water Dynamic Source Routing capabilities of AUSNet with a network consisting of two Falmouth Scientific Gateway Buoys, and one Benthos Deckbox. Utilizing an island as a physical barrier to communication, the two buoys where placed on opposite sides, and the deckbox was used on a boat at a point accessible to each. The AUSNet network configured it self to allow communication via the intermediary node. When the second buoy was moved out of the shadow of the island, AUSNet properly optimized it self to the shorter route. Additionally, the issue of maximum transmission range was attempted to be resolved, only to have the RF signal break due to wave conditions before detriments to the acoustic transmissions were found.

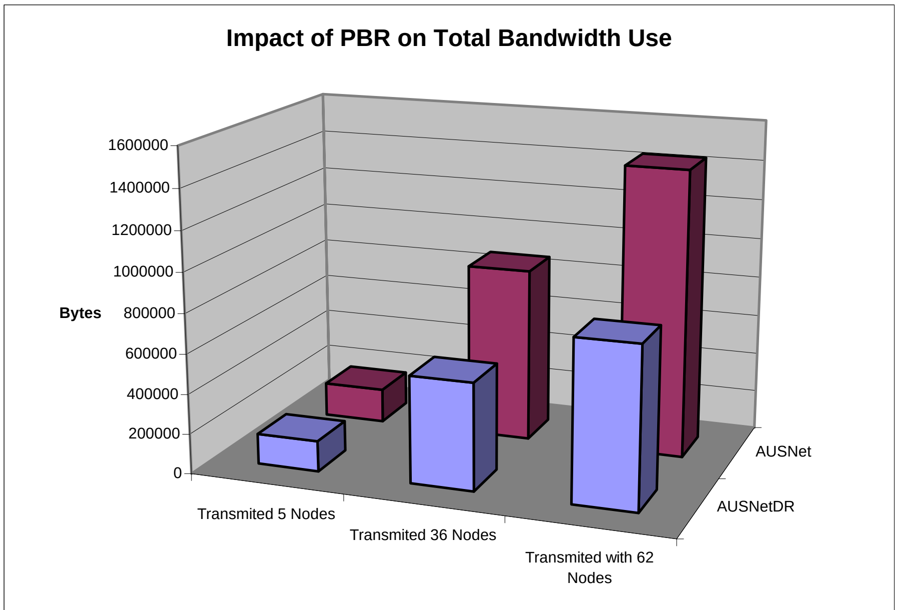
Testing within the Narragansett Bay, in Newport, RI, provided the first use of AUSNet within AUVs. AUSNet was integrated into 3 Solar AUVs and the Midsized Autonomous Research Vehicle prior to this May testing. AUSNet was used in operational testing of the SAUVs within the Stillwater Basin, and with the MARV in box runs in the testing range. Both MARV and SAUV status information was transmitted via AUSNet, and displayed in ASMAC. Unfortunately, due to hardware issues regarding the integrated Benthos modem within the SAUV, the anticipated relay test of AUSNet information from the MARV through the SAUV was not possible.

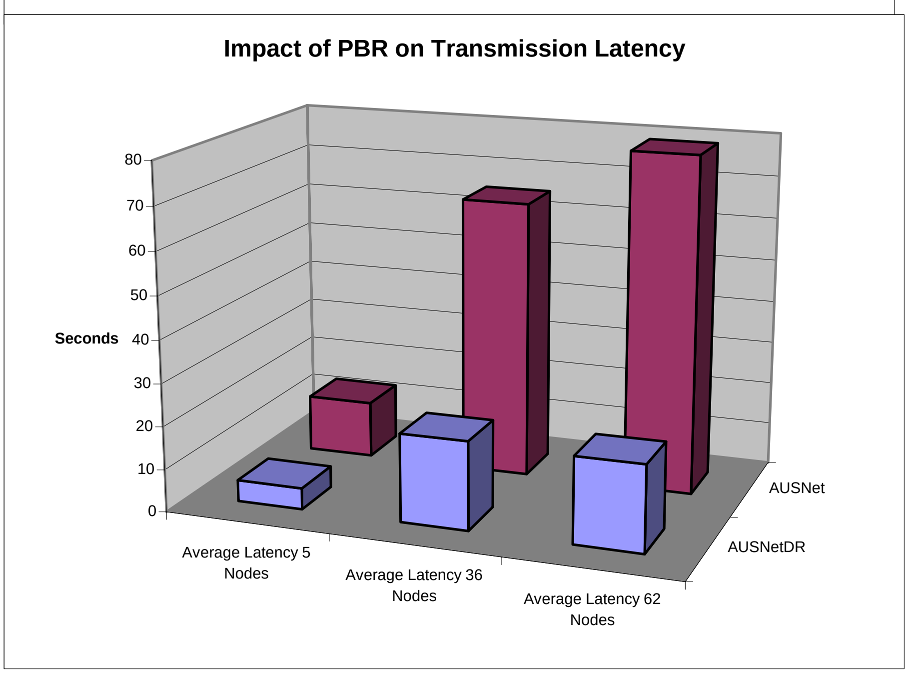
Testing at AUVFest 2005 in Keyport, WA, was less inspiring. The acoustic conditions within the Hood Canal operating area led to serious operational issues within the AUSNet Routing System. The conditions changed rapidly leading to quickly shifting routes and uni-directional communication. These changes to the physical medium led to interruptions of AUSNet Communication. This was alleviated to some extent via changes to the transmission settings of the Benthos Acoustic Telemetry Modems including lowering baud rate and transmission power.

AUSNet communications were further hampered greatly by the lack of access control to the physical medium, leading to significant signal interference and packet loss. An attempt to remedy this using the frequency hopped modem firmware from Benthos was unsuccessful due to failure of loading Benthos software over RF modems. Further testing with the new Benthos Acoustic Firmware is required to see if this will have the desired effect on signal collision.

Conclusions

AUSNet in PBR mode, known as AUSNetDR, offers significant improvement over AUSNet in DSR modes in Simulation. As the graphs





show, the prediction of optimized routes leads to nearly 45% improvement in required bandwidth and nearly 75% improvement in latency over DSR.

These improvements are due to a complicated set of factors. While the initial broadcast of information in PBR mode requires beginning overhead, the DSR mode must constantly update itself regarding the changing network state as AUV's move along their course. This leads to significantly more overhead in terms of Discover Route and Route Response Packets, as well as the very expensive rebroadcast of Data Packets when a link within a route is no longer valid. While the explanation of these factors in regard the effect on bandwidth is self evident, they are also attributed to the latency difference. Because the PBR system will already be aware of routes before they are needed, there is no waiting before transmission. Often, within DSR, a route needs to be discovered, leading a packet waiting in an outgoing queue until the route is found. Further, because DSR uses previously know routes, if a packet is required to be resent due to non-functioning route, the waiting for retry time outs also adds significant latency. An additional contributing fact to latency is that PBR utilizes the shortest route possible in terms of distance, while DSR uses the shortest route possible in terms of number of required hops, as it has no concept of distance.

As the AUSNet program continues to transition, two major obstacles remain. First to determine the effectiveness of the Benthos frequency hopping firmware with regard to packet collision within the water; and Second, to determine with a reasonable regard, the effective range of the modem technology for a given environment. To address both of these issues, further in water testing will be achieved through the developing acoustic network test range in the Sheepscot River, adjacent to the Technology Systems Incorporated office in Wiscasset Maine. The range will provide ample opportunity for research into these remaining issues.