A novel communication platform to enable the collaboration of Autonomous Underwater Vehicles

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Abstract - *A novel communication platform is introduced to enable the collaboration of a set of Autonomous Underwater Vehicles (AUV´s). The proposal is based on what we call the Virtual Quality-of-service Network (VQN) model, and the idea is to use it in order to provide the required network functionality and the semantic features that are needed for the collaboration. VQN is a semantic overlay network implemented as a distributed application by means of an object oriented middleware for distributed systems. Single-hop is the first option, but in case that no feasible single-hop route exists, a multi-hop route with the required QoS characteristics is attempted. Fuzzy Logic techniques are used to provide robustness in presence of imprecision in the measurement of network parameters. In this paper, a general description of the VQN model is presented, and experimental results about the network functionality enhancement are included to show VQN feasibility.*

Keywords: AUVs, underwater, overlay, VQN, collaborative, distributed.

1 Introduction

Underwater communication is an active research field. Even though the rapid growing of the wireless sensor networks in the recent years, research in the marine wireless sensor networks is minimal, and it is highly needed [8]. There are important physical, technological and economic differences between terrestrial and underwater sensor networks [12]. Limitations of nodes are more critical in the underwater networks than in a terrestrial environment. Main differences are in terms of cost, deployment, power, memory, and spatial correlation [2]. Underwater nodes are more expensive tan terrestrial nodes, terrestrial networks are deployed with more density, underwater acoustic communications need more power, underwater nodes require more memory to manage data cache when the channel is intermittent, and the lectures of the terrestrial sensors are correlated frequently, but in the underwater networks it does not happen due to the big distance between sensors. This opens the door for a wide range of applications and new relevant research areas in wireless networks. In [2], a list of open research topics for the data link, network, and transport layers is provided. The emerging communication scenario, in which modern underwater acoustic systems will operate in, is that in which underwater networks consist of both stationary and mobile nodes. Majority of the applications (collection of oceanographic data, environmental monitoring, navigation, tactic surveillance) make use of underwater vehicles and are based on the communication capacities between vehicles for the information exchange and coordination purposes [11]. 3-D networks of Autonomous Underwater Vehicles (AUVs) include stationary portions formed by anchored sensors and mobile portions constituted by autonomous vehicles. AUV's could be wireless, cabled, or remote-control, and therefore they have a multitude of applications in oceanography, environmental monitoring, and underwater resources studies.

2 Purpose

Control strategies are needed for autonomous coordination, obstacles avoidance, and direction strategies [2]. The integration of Underwater Acoustic Sensor Networks (UW-ASNs) with AUVs requires new coordination algorithms. Mobile vehicles could go to places where their data would be more useful. For instance, the sensor node density could be adaptively incremented in a certain area when a higher sampling rate is needed for a given specific phenomenon, connectivity holes due to node failures or channel impediments could be automatically detected, in order to require intervention of an AUV. Moreover, the AUV's could be used either for the installation and maintenance of the sensor network infrastructure, or to deploy new sensors.

The capacity limitation of some equipment used in the underwater communication environment (for instance sensors, embedded systems, video streaming etc.) makes difficult to implement complex network and collaborative protocols. The existence of these technological limitations makes impossible to perform the enhancement directly in the network nodes due to network equipment capacity limitations. The existing equipment may not satisfy the capacity requirements and other needed characteristics to implement better protocols, and therefore it is necessary to put the enhancement elements in external devices.

The objective is the design and development of a communication platform that enables the collaborative work of AUVs. This platform could be used to build a semi-autonomous underwater robot fleet. A fleet of small robots is more efficient and effective than big nodes, but underwater communication implies special issues. The basic elements for a traditional underwater communication are not sufficient in order to achieve the desired collaboration of underwater robots. A new platform is needed with more functionality.

The platform is used to communicate the AUVs and also is capable to perform distributed processes along the network constituted by the stationary stations and the semi-autonomous robots.

3 Related work

Several efforts have been done to provide an underwater collaboration platform, but most of them are focused on the collaboration algorithm only. In [13] a network protocol for the localization of multiple AUVs is presented. A network algorithm is proposed for communication in a group of AUVs deployed in a collaborative mission covering several squared kilometers. The algorithm is based on a time-programmed operation that permits the AUVs to locate each other by measuring the propagation signal delays among vehicles and interchanging location maps. In [15] a cooperative schema for underwater acoustic communication is presented, in which the intermediate nodes between source and destination act as cooperative messengers, in a way that an opportunity to save energy is offered.

We propose a solution based on a Service Overlay Network to provide a reliable and highly functional communication platform. There is a number of existing approaches to provide QoS by means of a P2P overlay [3], [4], [5], [6], [7], [9], [10], [17] and many others, but majority of them have been developed for applications that are very different from the underwater environment. Our proposal is to use the overlay P2P technology to provide a reliable and highly functional platform to enable the collaboration of underwater robots.

4 The communication platform

VQN is a semantic overlay network implemented as a distributed application by means of an object oriented middleware for distributed systems. The enhancement element that is added is isolated from the underlying network and independent from the application, and is not limited to just network operations but it could also be applied to provide additional semantic functionality.

The overlay network permits the implementation of three major components: object-oriented multi-layer routing, network functionality, and semantic functionality (Fig.1).

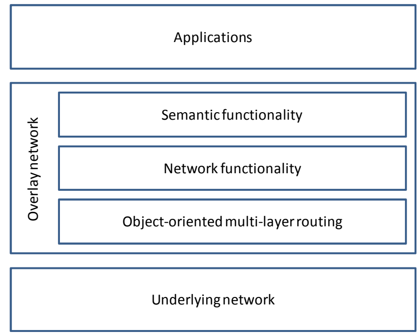

Figure 1. General structure of the proposed model

The overlay network is coupled to the underlying network by means of an object-oriented multi-layer routing component [16] that we call Inter-Domain Messaging (IDM). The objective of this multi-layer router is to provide an end-to-end data transport service that is independent of any network technology or protocol. The way in which the overlay network is implemented is as a distributed application that functions both as a client and as an object. IDM encapsulates messages and sends them as an object invocation. The overlay network is limited to do object invocations (local or remote) thru IDM. IDM is in charge of performing the connection, which is done in a transparent way. From the overlay network point of view, there is an existing connection to all nodes, regardless of their location. Due to the fact that all the objects (nodes) are directly accessible, a full mesh is established. The overlay network may perform routing functions on this virtual full mesh topology.

The network functionality layer is designed to implement the enhancement of the network characteristics. Two operating modes are considered for the participating nodes: Network Node (NN) and End Node (EN). The enhancement of network characteristics is based on the additional functionality provided by the NNs.

EN operations consist in the only possibility of receiving and sending packets from and to the network. NN operations include the same functions of an EN, but in addition they have the possibility to perform additional functions, both from the transport perspective (i.e. routing packets to other nodes) and form the applicative point of view (by instance, image, video or audio preprocessing, additional functionality in the semantic layer, etc.).

The path selection procedure is kept very simple in order to have a very low latency. The path selection decision is based on the QoS requirements determined for each incoming packet, and the route is constructed in a way that guarantees that those QoS requirements are satisfied. A direct link (single hop) between origin and destination nodes is the first option. If the direct link does not meet the QoS requirements for the packet, then a multi-hop route is attempted, making sure that the required QoS characteristics are met in every hop.

The routing table is constantly updated, but no overhead is added to the path selection process because the updates take place separately. The whole routing table update procedure is performed continuously, but the routing table is updated only when some change in the node list is detected (a new node is added, a node is excluded because is not available anymore), or whenever a drastic change (determined based on an established threshold) in the capacity or delay parameters of some route occurs.

The underlying network is monitored continuously. Capacity and delay measurements for each link are constantly taken. Capacity and delay forecasts are also calculated for each reachable node based on the historical behavior of the corresponding measured parameters. In the first implementation of VQN, the forecasts are calculated as moving averages using the three last corresponding measured parameters. Conventional statistical inference methods and neural networks will be investigated for future versions.

The routing table update process takes into consideration not only the capacity and delay measurements and forecasts, but it also includes Fuzzy Logic techniques in order to get a more robust model, which is more stable in front of uncertainties in the measurement of network parameters. Capacity and delay measurements are used as the inputs of the fuzzy model. The reasoning was done by using 9 inference rules, and a centroid method was used to defuzzify the answer. The answer provided by the fuzzy model is just a decision of whether the route is feasible or not.

Fuzzy Logic techniques can be used to enhance the way traffic is distributed in the network. A strict route selection criterion, combined with the occurrence of uncertainties, is the cause that good routes that should be taken are discarded, and that packets that should be sent, are also discarded. Some routes that are a little imperfect would be discarded by the traditional methods, but with Fuzzy Logic they are permitted to some range. This makes the system more robust and more tolerant to variations in the measurements. The result is that the route classification is richer, and offers the possibility to assign routes with a broader criterion. The idea is to assign routes that are possibly good, but that in other way would be classified as non-feasible and therefore they wouldn't be assigned.

Based on measurements, forecasts, and the feasibility answer provided by the fuzzy model, a routing table update is triggered only when a change is detected in the node list, or whenever a drastic change in the capacity and delay parameters is detected.

The functionality at the semantic layer consists on the identification of nodes semantically related. The overlay network offers the possibility for the participating nodes to perform diverse functions depending on their characteristics and circumstances. Those nodes with enough capacities (characteristics related to the battery level, process, memory, channel capacity) and that in one determined moment are in circumstances to do so (position, deepness, obstacles, etc.), could perform additional tasks. This additional functionality is not restricted to just network-type operations but it could also be extended to address additional requirements even at the semantic level.

5 Vision and control applications

Vision and control applications should include not only innovative and efficient vision and automatic control algorithms but also methods to achieve the collaborative work objectives as well.

Coral reefs are the most productive and complex ecosystems in the oceans. They have high biodiversity and structural complexity, comparable only to tropical rainforest ecosystems. This complexity imposes an inherent difficulty on what a scientist is able to do when trying to understand and characterizing the structure and functionality of the reef components. Once under the water, conditions are even more adverse. Vision tasks such as pattern recognition, optical object tracking, etc. are affected, among other issues, by noise in the images and illumination changes. It is necessary to implement algorithms that should be robust enough to overcome the distortion and movement problems due to the environment. These algorithms may be computationally expensive to be performed by a single machine.

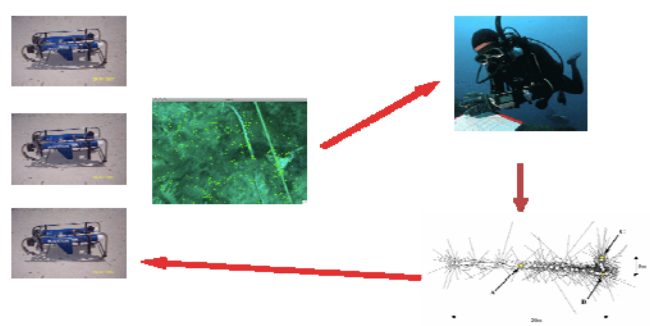

Figure 2. Schema of the usefulness of visual integration to generate a map for divers, based on the information provided by the networked AUV's

Our proposal is to integrate the vision system in the underwater robots and perform the image processing and pattern recognition tasks in a distributed environment [1]. We propose the use of state of the art algorithms for camera-based real time simultaneous localization and mapping (SLAM) in the coral reef scenario. Visual SLAM algorithms offer a mathematically rigorous way to locate in a 3D space the measurements provided by the AUV video camera, which can be used to provide positioning information and a map of the surroundings in addition to the video stream. The transmission of one image or its local processing could depend on the necessity of processing it in the server, delegating its processing to a remote entity, or simply transmitting it to that location. The grade of processing depends on the availability of process capacity in the intermediate nodes and the traffic in the network. Each stream should be processed accordingly to its type of information. If the processor is loaded with the processing of the image may slowdown the network, so there's a need for a processing and distribution policy to guarantee QoS. The capture of information and its transmission need to be coordinated by a scheduler. Communication policies definition is based on the urgency and temporality of the actions, and could be also based on semantic similarity.

Vehicle control functionalities regard to the actions that are needed based on the performed vision analysis. In our group we have already experimented on telerobotics by using visual servoing techniques for automatic robot motion control [14]. The location and control of robots could be done efficiently by using the information of the cameras. Control functions such as going up or down, going round an obstacle, ask for another robot's assistance, etc. could be done efficiently when based on a reliable communication platform that interconnects all the participating nodes.

6 Experimental results

In [16] we provided latency and throughput benchmarks with regards to the object-oriented multi-layer routing component (IDM). In this paper we provide some preliminary numbers about VQN feasibility in terms of the network functionality enhancement.

We conducted an experiment for a 20-node full-mesh network, with 56 (±3) kbps links and 150 (±3) milliseconds delay. Capacity and delay measurements were obtained with a precision of 90%. The software prototype was written in the C++ programming language, complemented as a distributed application by means of the use of Zero C ICE [18], an object-oriented middleware for distributed applications. Development was done in an IBM-compatible PC with an Intel P4 2.26 GHz processor, running Windows XP professional with SP3 as the operating system, Visual Studio 2005 SP1, and ZeroC ICE v3.3.0.

We defined two metrics in order to compare results. First metric is the coverage, calculated as the number of good paths selected (number of packets that were sent thru a route with the required QoS characteristics, either single-hop or multi-hop path) divided by the total number of packets that have direct route with the required QoS characteristics. Second metric is the effectiveness, calculated as the numbers of good paths selected divided by the total number of paths that were assigned. Both metrics (coverage and effectiveness) are expressed as percentages.

Numbers show that VQN helped to get a better coverage and a better effectiveness. The experimental results are shown in Table 1.

Table 1. Coverage and effectiveness experimental results

	Reference	VQN
Coverage	100.00%	103.42%
Effectiveness	27.06%	35.78%

VQN was able to provide an increment in the coverage rate because for some packets there was not a direct (single-hop) path available between the origin and the destination for that particular packet, but there was at least one multi-hop path with the required end-to-end QoS characteristics that could be used instead. The 100% reference number that is used for the coverage comparison means that just single-hop QoS paths were used. When using VQN in our experiment, an additional 3.42% of (multi-hop QoS) paths were found and used.

The effectiveness rate is associated with the number of packets were sent thru paths with the required QoS characteristics. The 27.06% reference used in this case was obtained in the experiment when the rough measurements of the network parameters were used for the routing decision. This number is rather low in our experiment due to the injection of uncertainties in the actual link capacities and delays and also because of the measurement imprecision that was considered. The use of Fuzzy Logic techniques in VQN helped to raise that number up to 35.78%.

7 Conclusion

The VQN model has been proposed as an external network enhancement mechanism to be used as a platform to enable the collaboration of AUVs. Early experimental results about the network functionality enhancement show VQN feasibility.

The solution is stated as an external network enhancement approach. The problems in the underlying network are not attacked directly, but the enhancement is done externally with no intervention of the network nodes. Enhancement is done by optimizing the use of the network (finding the best path with the enhanced network functionality) and by optimizing the information (some nodes have the possibility to perform additional functions), and the enhancement element is not limited to just network operations but it could also be applied to provide additional semantic functionality.

A reliable and functional communication platform could be used as a basis of efficient vision and control collaborative operations.

Acknowledgments

This work has been funded by the Spanish Ministry of Science and Innovation under project DAMA TEC2008-06553 and the Regional Goverment of Castilla-La Mancha under project RGRID PAI08-0234-8083 (authors from Universidad de Castilla-La Mancha); and by Fundacion Carolina and Universidad Anahuac Mayab (authors from Universidad Anahuac Mayab).

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