Creating a maritime wireless mesh infrastructure for real-time applications

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***Abstract*—Advances in computing and networking technologies have revolutionised the way people communicate using interactive real-time applications such as instant messaging and audio and videoconferencing. This category of applications is nowadays readily available to users in terrestrial areas with high speed Internet connectivity. The aim of this work is to investigate the provision of IP-based network connectivity onboard sailing vessels in order to support real-time communication applications. More precisely, instead of the expensive and high-latency satellite communications solutions widely deployed in the maritime industry, we propose the use of long-range wireless networking technologies for creating a vessel-to-shore mesh network that can be used to form an infrastructure for the provision of telephony services based on Voice-over-IP (VoIP).**

Keywords: maritime network; Voice-over-IP; WiMAX; mesh network; real-time communication

I. Introduction

Growing demand from crew members and passengers is urging vessel operators to offer various onboard communication solutions. Such services are currently possible through satellite communications and in spite recent improvements satellite-based network connectivity is still characterized by low capacity, high latency and high operational cost. Some of the most widely used applications in today's Internet (e.g. videoconferencing and Voice over IP) are based upon real-time communication (with stringent timing requirements) and as a result cannot operate properly and cost effectively (considering the amount of data they generate) in networks exhibiting the abovementioned characteristics.

Recognizing the penetration and extensive use of real-time applications nowadays, along with the increased need for such communication facilities when users are away from their normal place of residence, with this work we aim in the development of a platform that enables the provision of real-time applications, with a particular emphasis on Voice over IP (VoIP), over maritime-based IP networks. Such networks will be established using advanced wireless networking technologies (e.g. WiMAX) which are far superior (in terms of capacity, latency, and cost effectiveness) than the satellite communications predominantly used today.

The distinct nature of the maritime-network and the strict timing and reliability requirements associated with real-time applications raise different scientific and technological challenges. These stem from the fact that a subset of the vessels are moving, which results in a constantly changing network topology and also implies that connectivity will occur intermittently. In a sense, a "moving" wireless mesh network will be created with participating vessels considered as the nodes (sending own data and acting as intermediaries for data from vessels further away from the shore) and the land-based stations acting as gateways to the services offered.

In the rest of this paper, we will first describe the technologies that our work will be based upon and then provide a detailed description of the system architecture and operation procedure. Finally, we will present our conclusions so far and the next steps in our work.

II. Background

The provisioning of highly demanding real-time applications within a distinct operational environment, which in our case is a continuously changing wireless network over sea water, is expected to bring up some interesting challenges and unknown issues. We briefly study the relevant technologies before providing an overview of the current status of IP-based maritime communications.

A. *Wireless Mesh Networks*

Recent advances in wireless networking technologies have resulted in standards and equipment that significantly increase the distance over which point-to-point and point-to-multipoint IP connections can be established. For example, the 802.16 standard (WiMAX) [1] theoretically allows for 70Mbps connections between devices placed 40km apart and the recently approved 802.16m (WiMAX-2) [2] even more; connections over such distances can significantly enhance network coverage.

In addition, and in order to further enlarge its coverage area, the intended network will comprise of both vessel-to-shore and vessel-to-vessel connections; as a result, it is expected to share many characteristics with a wireless mesh network (WMN). A WMN is a dynamically self-organised and self-configured wireless network consisting of nodes that automatically establish ad-hoc network connections forming a mesh topology [3]; our network will interconnect vessels and base stations over single or multi-hop connections.

One popular application utilizing mesh networks is VoIP which has proven to be quite useful in rural areas that lack traditional telecommunications infrastructures. Studies made for the performance of VoIP over mesh networks showed that link capacity drops quickly as the number of hops required to reach a base station increases [4] and that current routing protocols for WMNs are not optimized for VoIP traffic [5]. To overcome those difficulties, different optimizations and improvements have been proposed such as VoIP packet aggregation [6] and header compression along with a routing algorithm that switches to different network paths to maintain call quality [7].

An important characteristic of the expected mesh-like network is that vessel mobility will result in relatively frequent topology changes; issues faced in Mobile ad-hoc Network (MANET) and Vehicular ad-hoc network (VANET) environments may also arise. The opportunistic network paradigm holds too; vessels are expected to experience intermittent connectivity. Having access to information about vessel movement can be highly beneficial for network topology building and planning; the Automatic Identification System can prove to be highly beneficial for our purposes.

B. The Automatic Identification System

The Automatic Identification System (AIS) [8] is an automated tracking system that is used for identifying and locating vessels. It is a legal requirement that vessels over a certain size broadcast critical information about their identity (Maritime Mobile Service Identity (MMSI)) and location. Aimed primarily in increasing safety, the AIS also provides vessel telemetry data such as speed, course, rate of turn, destination, and estimated time of arrival at destination port. The data transmitted is received by vessels and monitoring stations in the surrounding region which may extend to tens of kilometers.

In our case, we plan to utilize the AIS for acquiring information about a vessel's position and course. Data received through the AIS can be used to create the network topology and quite importantly predict upcoming topological changes, allowing us to proactively reallocate resources, optimizing the performance of real-time applications. Information on vessels outside but near and plying towards the network coverage area is vital during our system's operation.

C. Maritime networks

The multitude of communication applications available today, create a need for low-cost communication and high speed connectivity even when vessels are quite far away from a port. As the most obvious option, internet connectivity onboard sailing vessels is provided through satellite-based broadband technology. This usually caters for email and web browsing from the relatively small number of computers installed on the vessel. After recent developments, a service that combines GSM and satellite technologies allows passengers to use their mobile phones on cruise ships; such a solution is quite useful but at a very high cost for the end-user. As already mentioned, communication through satellites is expensive (since traffic is metered) and of relatively low capacity; the unavoidably high latency involved (over 500 milliseconds), implies that satellite connectivity is not really suitable for interactive applications with real-time characteristics e.g. voice and video [9, 10].

Recently, there has been some research activity in maritime-based IP networks; researchers, are trying to provide IP connectivity to vessels by utilising wireless networking systems [11]. Their early results, as well as the approaches proposed in their work are quite promising. Their findings may provide algorithms that resolve network establishment as well as routing issues; these could be utilised in our work to build the network model on top of which we aim to provide a VoIP call management framework that utilises that network in an efficient manner. The US Navy has made some studies that are closely related to our research [12].

III. SYSTEM ARCHITECTURE

The rationale behind our work is to initially study the issues involved in building a high-speed maritime-based wireless network infrastructure and later concentrate on utilising innovative techniques in the development of a novel platform that supports low latency VoIP communication over this infrastructure.

The technologies presented in the previous section have been combined in a novel architecture whose major components (as depicted in Figure 1) are: the Connectivity Scheduler, the VoIP Gateway Controller, and the Vessel VoIP Proxy. These components (described in detail below) interact with each other for maintaining a high level view of the network, monitoring changes in its topology and provisioning VoIP connectivity services over it.

A. The Connectivity Scheduler

The Connectivity Scheduler (CS) is essentially the entity managing the whole system; it is responsible for maintaining the current network topology and planning for changes in it, while overseeing the allocation of resources to the vessels. There are two distinct subsystems within the Connectivity Scheduler: the Network Manager (NM) and the Resource Manager (RM).

The Network manager's role is to keep a consistent and up-to-date snapshot of the Wireless Maritime Mesh Network (WMMN). This is achieved by acquiring and processing AIS messages received from different sources; such sources are AIS receivers sending their data directly to the NM or online services that offer such information.

Being aware of ship mobility patterns allows the NM to predict network topology changes which will occur every time a vessel enters, or sails away from, the network coverage area. As a result of these movements, the network coverage area may extend or reduce in size; obviously, these changes have an impact on resource allocation. The role of the RM is precisely the continuous analysis of the network and the application of various algorithms that allow for resource provisioning in a fair and optimum fashion; such algorithms will take into account the role of each vessel within the network topology.

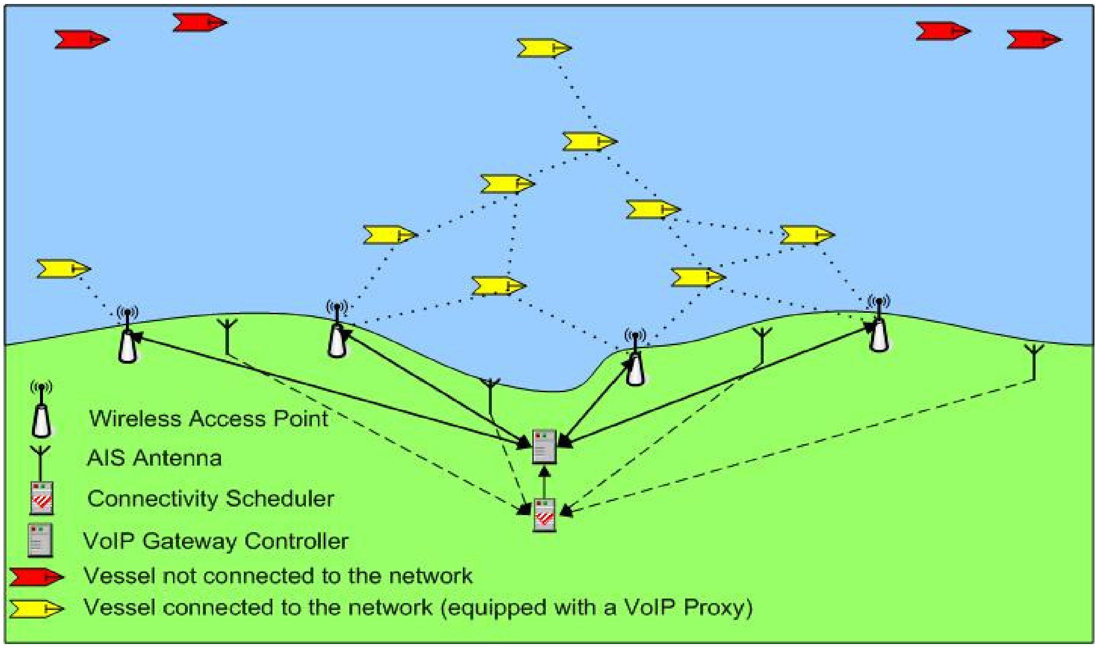

Figure 1. System architecture

B. *The VoIP Gateway Controller*

The VoIP Gateway Controller (VGS) is a system installed at the shore and consists of a SIP-based proxy that works in conjunction with, and controls access to, a PSTN gateway. As the VGS is in control of a finite resource, it is in charge of allocating lines to vessels for PSTN access.

Line allocation is based upon a number of criteria which relate to the current status of the network as well as past activity. In the former, vessel location (as well as course and speed) is critical and the VGS is responsible for enforcing the Call Admission Control policy dictated by the Connectivity Scheduler to prevent call-related traffic from exceeding the threshold where the network can operate reliable. In the latter, we aim to apply the application level Call Admission Control policies that we developed [13] that use historical information to 'enforce' a fair share of line usage.

C. *The Vessel VoIP Proxy*

The Vessel VoIP Proxy (VVP) is each vessel's SIP-based VoIP proxy; under ideal circumstances this entity is also the vessel's telephony system (PBX) on which all the phones onboard are connected. The VVP incorporates enhanced functionality via a control protocol for exchanging information about the calling capacity allocated by the system's managing entities.

IV. SYSTEM OPERATION

A key feature of the proposed system is an intelligent call management framework that makes predictions about upcoming network connections, their duration, and their capacity. A vessel is deemed to be part of the network when it can reach a shore-based station either via a direct connection (vessel-to-shore) or via a multi-hop connection (vessel-to-vessel).

A high-level communication protocol will allow for the cooperation between the different VoIP entities participating in the WMMN; key information to be provided includes demand predictions, call capacity capabilities as dictated by the currently available (or soon to be available) connection and CAC policies, and routing information.

The interaction between the various system entities is depicted at Figure 2. The Connectivity Scheduler continuously processes AIS information so that it always has an up-to-date snapshot of the network. The topology data along with resource allocation information is 'fed' to the VoIP Gateway Controller. The VGC processes this information and applies Call Admission Control policies for controlling access to the PSTN gateway; these are crucial in maintaining a fair share of resources. Using a dedicated messaging protocol, the VGC also communicates line allocation information to the Vessel VoIP Proxies; in turn, the VoIP proxies allow the number of calls permitted with media data flowing once a call is established.

It is important to note that media data may only be exchanged once a network connection is in place; one may however opt to transfer control data (which is negligible in terms of volume) using the satellite connection e.g. for notifying that a connection is imminent. Utilising the Connectivity Scheduler, the Call Management framework will be able to improve the performance of VoIP applications by reserving relevant resources on behalf of vessels in need of them. The framework can even allocate resources before a ship enters the network coverage area; the connectivity scheduler is able to provide data regarding approaching vessels.

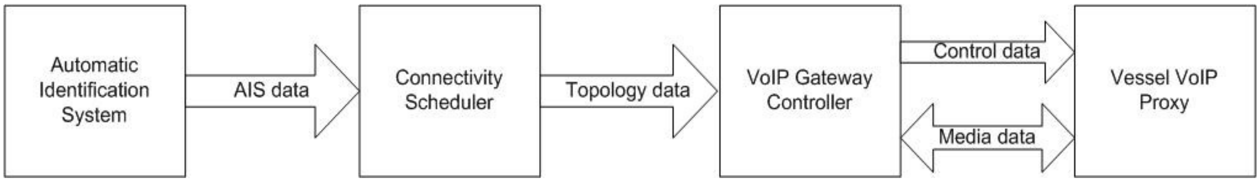

Figure 2. Component interactions

V. CONCLUSION AND FUTURE WORK

As far as we are aware, we are the first to propose an approach that will offer inexpensive IP-based connectivity to moving vessels, optimized for VoIP. A real deployment of this architecture will revolutionize the way people on vessels communicate with people on land. However, we should emphasize that we predominantly aim to identify issues and propose solutions for the improvement of real-time traffic over a maritime-based network, assuming the existence of the network infrastructure; thus it is important to note that other efforts only concentrate on building the network infrastructure. Our work will help identify issues from a real-time traffic perspective, and potentially suggest enhancements to the technologies involved in building the underlying wireless network, so that a useable system can be architected and subsequently deployed for the benefit of the maritime industry and its staff and passengers. Our immediate future activity involves the development of our architecture for evaluation and the investigation of the issues already described above in a simulated environment.

Although primarily aimed for the provision of real-time services, the proposed architecture can be used to facilitate delay-tolerant communications for voice messaging [14] or delivery of other kinds of data [15]. Being able to predict connectivity may allow a service to estimate when data will be delivered and based on how critical it is, decide upon the most appropriate and cost effective delivery medium. Such potential enhancements further highlight the prospective usefulness of the implementation of the system we proposed.

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