Computer Science

Evaluating the Effectiveness of a Space-Based AIS

Wesley F. Willick

Sir Winston Churchill Collegiate and Vocational Institute, Thunder Bay, Ontario

DOI: 10.13034/cysj-2014-009

Although certain boats can avoid collisions by communicating with each other and stations on land, a network of satellites above the earth's poles could give boats all over the planet that ability. The current system for collision-avoidance involves radio signals sent from boat-to-boat and boat-to-land. But the new system, based in space, would put satellites in the line of communication. It would increase the capabilities of boats to detect each other and for land-stations to detect boats with faulty or suspicious voyage information. Adding satellites into the communication equation could make contemporary collision-avoidance technology available on a global scale.

Bien que certains bateaux peuvent éviter les collisions en communiquant un à l'autre et avec les stations à terre, un réseau de satellites pourrait donner bateaux sur toute la planète cette capacité. Le système actuel pour éviter l'abordage utilisent les signaux radio envoyés par bateau à bateau et bateau-à-terre, mais le nouveau système, basé dans l'espace, mettrait des satellites entres les communicants. Il augmenterait les capacités des bateaux à détecter entre eux et pour les stations terrestres pour détecter les bateaux avec l'information de voyage défective ou suspect. En ajoutant les satellites dans à la communication, on pourrait rendre la technologie d'évitement des collisions contemporain disponible à l'échelle mondiale.

Abstract

This paper will discuss how a space-based AIS will function, along with the problems with making the system reach its full potential. Section I will describe what an AIS is, and how the current Terrestrial based AIS works. Section II will explain how a space-based version of AIS will function. Section II will be divided in two parts; the first explaining how a terrestrial AIS can be transferred to space. The second part will deal with how many satellites will be necessary and at what altitude those ought to be. Section III will look at problems that may occur, dealing mostly with detection probability. Section IV will be a final evaluation and Section V includes references.

Section I: Background and the Terrestrial AIS

Since radio was developed, all ships capable of high seas travel have been equipped with one. The Captain or Navigator would be able to contact other ships or harbours/ports and inform them of their approximate location, speed, and heading. However, radios were limited because they did not have enough power to transmit a clear message more than a few nautical miles. As radio technology improved, messages were sent further. This combined with the increasing amount of vessels- suddenly there is a need for systems that can automatically manage all of the data (location, velocity, heading, voyage information). The systems also need to better organize the passage of individual vessels while making seas safer for all vessels. From those ideas came the Automatic Identification System (AIS), a network of transponders and receivers on individual ships that communicate with a station on land and other ships in range.

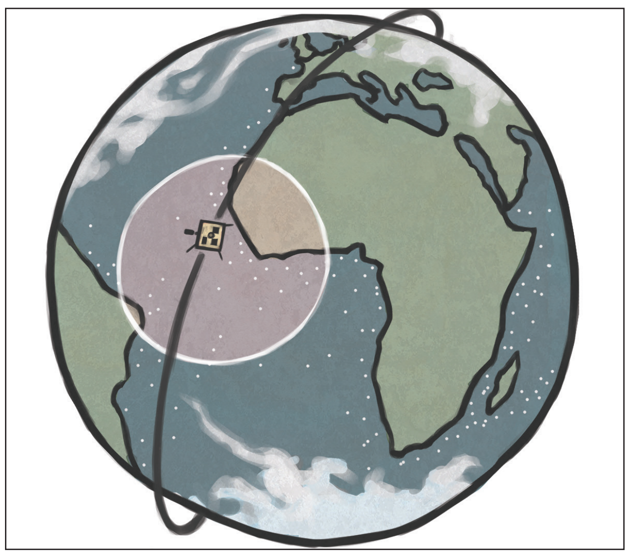

Figure 1. An AIS satellite and it's field of view

This system allows ships a direct link to any other ship that could be in need of help, or offering help, or is simply "too close for comfort." The receiving station on land can then sort through information that it receives and alert anyone if two ships are nearing a collision or if certain voyage information seems suspicious, such as a ship supposedly carrying clothes stopping at a harbour that only deals with food. The AIS only works great if the ships are within range of each other and the land station. That is where the problem of a terrestrial based AIS lies, conventional radios do not have enough power to transmit over long distances or past the horizon. But a space-based AIS using satellites can.

Section II: Space-Based AIS

Part I: The difference between the terrestrial and space AIS is miniscule. The terrestrial version works by ships communicating with each other, and relaying that information to a mainland station. The only difference is that the space-based AIS uses a network of satellites to monitor the waters in a certain area. Usually each satellite has a field of view (FOV) of approximately a few thousand nautical miles. Terrestrial AIS and Space AIS both rely on a small group of ships communicating between each other as well as with the satellite/mainland station. The range in which the ships can communicate with each other for both types of AIS is the same, approximately 40 nautical miles[1].The range is the same for both versions because it is simply ship-to-ship communication without the use of a satellite, even for the space based version. Both versions use the same coding/structure. The difference between terrestrial AIS and space-based AIS is how the information packets, from each ship, reach the mainland. In terrestrial AIS, the information packets would be sent by radio to the mainland, greatly reducing the possible range of transmission. In the space-based version, the information packets are sent directly to a satellite where the AIS is located and then transmitted to a mainland station.

Part II: The AIS information is broadcast in small packets in intervals of approximately 26.67 milliseconds. Each packet is 256 bits and transmitted at a rate of 9600 b/s (bits/second) [2]. These packets are arranged in a Self Organized Time Division Multiplex Access (SOTDMA) region. The SOTDMA can account for time delays of no more than 12 bits, making its range approximately 200 nautical miles. However, since the radio range is limited, the coverage is limited to the previously stated 40 nautical miles.

Two messages from different ships are capable of arriving at the same time and effectively cancelling each other out, so the SOTDMA has a protocol that prevents the bursts of information from colliding. Each Time Division Multiplex Access (TDMA) sequence has a frame that is 60 seconds long with 2250 slots for messages[2]. Each time a ship sends an information burst, the burst also reserves another slot for its next transmission. This method of reserving slots reduces the chance of messages colliding. The time between broadcasts from each ship varies between 2 seconds and 6 minutes. The amount of time between transmissions varies depending on the speed and location of the ship.

If a ship were moored at port then it would transmit every 6 minutes. The further from shore a ship is the shorter the transmission period. Each burst has a set structure with several parts each having an allocated amount of data:

Each part of the TDMA sequence has a certain task. For example, the Training Sequence is a test run for the message to make sure it will be detected. The Start Flag is where the data burst from the ship announces its presence to the TDMA system. The Data part is where the actual data is located in the burst. The FCS is where the data burst reserves its next location in the TDMA frame. [1] The Time Buffer is a small amount of space designated for mishaps or slow connections allowing the messages some leeway in their arrival.

Part	Allocated data size
TrainingSequence	24 bits
Start Flag	8 bits
Data	168 bits
FCS	16 bits
End Flag	8 bits
Time Buffer	24 bits

The purpose of using satellites for the AIS is so that a global coverage and tracking system for all ships, no matter where they are, can work efficiently. For that to happen there needs to be a large group, or "constellation" of satellites in Low Earth Orbit (LEO) [2]. The satellites would most likely be at altitudes between 600 and 1000 kilometres[1]. Considering that altitude and adding in the rather large span of a Very High Frequency (VHF) radio, each satellite can have a monitoring FOV close to several thousand nautical miles. Most of the satellites would be placed in near polar orbit, only deviating by a few degrees. This type of orbit, when viewed with respect to the Atlantic and

Pacific Oceans allows the satellites to have a much larger amount of time over major shipping routes than if they were in an equatorial orbit.

Section III: Potential Problems and Troubleshooting

Problem 1: The space-based AIS is designed so that the satellites communicate with a group of ships that are all within range of communicating with each other using VHF.

Since all the ships in this group are communicating slot times for the TDMA frame, message collisions are almost entirely avoided. The problem is; what happens when there is a single ship, or even a smaller group of ships lying outside the communication range of the main AIS group of ships but still in the field of view of the satellite for that area. Now there is one group that is efficiently communicating and avoiding message collisions, but there are also messages that are not organized to fit into a time slot coming from the outlying ships. This problem increases the chance of a collision of messages from two different non-communicating groups. Depending on the number of ships within the satellite FOV, the chances of two or more SOTDMA regions transmitting messages that overlap the messages of the other SOTDMA region will increase or decrease.

The more SOTDMA regions, the higher chance of collision, but more vessels does not necessarily mean more collisions. If there is a large number of ships but they are close enough to form only two or three SOTDMA regions, then the chances of a collision are lower then if there were fewer ships that were spread further apart in multiple SOTDMA regions [3].

Problem 2: Another problem with a space-based AIS is the Doppler Effect. Because of the large variance between the velocities of the ship and the satellite, Doppler shifts of approximately -4 kHz to +4 kHz can be experienced, resulting in a maximum relative Doppler shift of 8 kHz. The formula below can be used to calculate the Doppler shift for a satellite in a 600 km LEO with a uniform ship distribution[1].

$\Delta f = v/\lambda, \qquad \lambda = c/f$

λ = wavelength and v = the velocity of the satellite

Problem 3: Another problem is that there is no set type of transmitter that is mounted on ships. Typically, there are two types of antennas commonly used: a $\lambda/2$ dipole and a $5\lambda/8$ end-fed monopole, with gains ranging from 2 to 4.5 dBi. However, not all ships will have one of these two antennas mounted, some ships may not be able to communicate properly because they have a less powerful antenna that can not transmit/receive the messages properly[1].

Problem 4: Other terrestrial VHF systems may cause interference. This type of interference is probably unavoidable and will mostly occur in areas with a large amount of VHF Public Correspondence channels (VPC). However, there has been very little research done with this type of interference, so the actual effects are not known[1].

Section IV: Conclusions

A space-based AIS system holds promise for a global ship detection and surveillance system in the upcoming years. The SOTDMA regions that have an average range of 40 nautical miles combined with the possible collisions caused by multiple SOTDMA regions in the same FOV of a satellite are the main problems to be overcome for the space based AIS to function as an efficient system.

Having a constellation of satellites in a near polar LEO is the best way to ensure all major shipping areas in the world are fully covered. A near polar orbit will keep the satellites over top of the Pacific or Atlantic Oceans as well as the Arctic Ocean and a small portion of the Indian Ocean.

The Doppler effect, terrestrial VHF interference and the possibility that not all ships will have a good enough antenna are very minor issues when compared to the problem of message collisions from multiple SOTDMA regions within a satellite's FOV. However, when these three problems are all present within the system, there will be major issues when it comes to the final implementation of the space-based AIS.

Section V: References

[1] Cervera Ginesi, "On the performance analysis of a satellite-based AIS system", Acta Astronautica (2008), Accessed March 13, 2014

[2] Erikson et al, "Maritime traffic monitoring using a space based AIS reciever", Acta Astronautica (2006), Accessed March 13, 2014

[3] Hoye et al, "Space-Based AIS for global maritime traffic monitoring", Acta Astronautica (2008), Accessed March 13, 2014