Satellite reception of AIS signals

**SHIP TRACKING** The terrestrial AIS network was never designed with space reception in mind, and this poses some interesting challenges when it comes to detect AIS signals from LEO satellites. Dr Ian D’Souza explains the technical issues surrounding the detection of AIS from space.

Ian D’Souza

The reception of Automatic Identification System (AIS) signals transmitted by Class A type transponders on board sea going vessels and from shore base stations has been demonstrated by several companies as well as the US government. That AIS signals could be detected from low earth orbit (LEO) and thus used for a more global awareness of ship movement was postulated years ago, post September 11 2001, by the US Coast Guard [1], with initial thinking along these lines dating back perhaps ten years. In the years since, a few companies and institutions have launched some type of AIS receiver into LEO, including the Naval Research Lab, Orbcomm, SpaceQuest and COM DEV/ExactEarth. It is expected that soon some European AIS satellites will be tested.

Any space based AIS receiving system will have some degree of latency due to the orbits of satellites and locations of ground stations at which satellites download the received data. Thus AIS signals received in orbit are not intended to provide real-time navigational information, but is able to provide situational awareness. In addition, a LEO satellite will fly over any given area in a time measured in minutes, thus continuous monitoring of any particular area is also not possible. These effects must not be seen as short-comings of the system, because as few as six satellites can cover every area of the globe with refresh rates of two hours typically (in equatorial regions), and much lower rates at the higher latitudes. Adding more satellites increases the refresh rate.

Compared to a typical terrestrial AIS receiver that is constrained by the curvature of the earth, the vantage point of a space based receiver provides a truly bird’s eye view of ships carrying AIS transmitters (Fig. 2).

The utility of detecting AIS messages from orbit, where the field of view of a typical LEO satellite is on the order of 5,000 km diameter, is obvious: a very large area can be monitored simultaneously, providing a large scale picture of maritime operations.

Ships can now be seen far from coastlines. Applications to long range search and rescue, environmental monitoring, wide area security and traffic management on longer time scales come to mind.

**AIS time slots**

The AIS system was designed as a mariner’s aid to navigation and to assist in collision avoidance while providing awareness of the identity and movements of nearby ships. Typical AIS systems automatically transmit and receive information between nearby ships, such as a ship’s identification, speed, heading, latitude/longitude, rate of turn and course over ground.

The ships maintain this communication with each other using a scheme of transmissions. Each ‘frame’ of 60 seconds is composed of 2,250 individual time slots in which a ship can transmit, on two separate AIS channels, creating a total of 4,500 slots, Fig. 3. These 4,500 slots, each of which are 26.67 milliseconds long, are the time slots in which an AIS message, of the type shown in Fig. 4, can be transmitted. Special AIS messages that occupy multiple slots can be used to transmit longer messages.

This slotted, time-sequenced structure is used so that ships do not transmit messages at the same time. The AIS protocol requires that ship transmitters ‘reserve’ their transmission slots ahead of time (the AIS receivers do this automatically and transparently to the ship crew) in a self-organizing manner. With slots being reserved, ships do not transmit at the same time slot. This method of transmission is called Self-Organized Time Division Multiple Access (SOTDMA). A group of ships within AIS transmission range of each other (typically about 50 nautical miles, a region called a ‘cell’) organize their AIS messages using SOTDMA to communicate with each other. This protocol can handle over 1,000 ships that are clustered together in a cell. The theoretical maximum is 4,500 ships, however, for technical reasons the number is less than this. There is no problem if the ship numbers increase so as to fill the 4,500 transmission slots. In this case the ship AIS transmitters automatically reduce their transmission power and work within a smaller cell, reusing the slots occupied by the weaker transmissions from ships that are furthest away. These cells of self organization, of the order of about 50 nautical miles in size, work very well on the oceans and waterways.

However, examining Fig. 2 again, one will notice that the field of view of the satellite can be over 2,700 nautical miles in diam-
eter (5,000 km). Thus a very large number of SOTDMA cells will be received at the satellite. Ships that are re-using the same slots in different cells will cause overlapping transmissions that arrive at the satellite. This is the main problem associated with satellite reception of AIS signals. It may be the case that, once in a while, purely on a statistical basis, a 26.67 ms slot will contain one single message, or one much stronger message signal compared to the others in the same slot. This will allow for relatively simple detection of the strong message in the slot. However, in the case where there are many ships in the satellite’s field of view, the probability of the finding slots that contain single messages, or one message that is much stronger than the others becomes very low.

**Ship message detection rate**

Thus the problem of receiving AIS messages from space comes down to how well a receiver can discriminate the strongest signal from background signals to extract AIS messages. The approach to receiving as many messages as possible requires either the ability to work with signals that are only slightly higher in gain than the background, and/or to observe the scene in the field of view for as long as possible. The idea of long observation times is simply that, statistically, if one waits long enough, the satellite will receive a transmission from each ship in the field of view.

In any case, all messages received at the satellite are very weak because ships transmit with very low gain towards the sky, and thus it is important to verify the Frame Check Sequence (FCS) (Fig. 4) for each message received. Not doing so can result in incorrect AIS messages (incorrect location, or speed, or heading, or ship ID etc.)

The ability to detect signals only marginally greater than the background while still ensuring that the FCS is validated is strictly a problem of receiver system design capability. The better the system design, the better the detection rate. Unfortunately, long observation times depend only on how long the ships remain in view as the satellite passes overhead. Typically this is of the order of 5 to 10 minutes for LEO satellites. One can increase the observation time by adding more satellites so that as one completes its observation, another may be just coming into view, but this necessarily drives up the cost of the constellation of satellites and introduces extra delay that retards the freshness of data. Another way is to increase the altitude of the satellite to obtain a large field of view. This unfortunately does not add much time of observation, and has the detrimental side effect of increasing the number of ships in the field of view.

In some areas of the world, such as the South Pacific, near Tahiti, the ship traffic density is very low and there is no problem of slot congestion as viewed from space. In other areas of the world, the slots may be oversubscribed by a factor of 10 to 20 as seen from space. In these areas, waiting for strong signals by using a lengthy observation time is not very useful. In these instances, the ability to extract a signal from the overlapping messages is key.

Depending on the satellite AIS receiver and satellite system design, validated (i.e. FCS verified) AIS message detection rates can vary anywhere from 3 messages per second for a simple AIS receiver to 42 messages per second per satellite on average for a sophisticated system. Since there are only 37 of the AIS 26.67 ms slots in one second of time, extracting more than 37 messages per second implies that sophisticated systems can sometimes extract more than one message from a single slot. It is important when evaluating any satellite based AIS system to compare only the number of validated AIS message detection rate.

**References:**

[1] Private communication with George G. Thomas, Office of Global Maritime Situational Awareness

**The author:**

Ian D’Souza, Ph.D., Microsatellite Mission Scientist, COM DEV/ExactEarth Canada