A SYSTEM TRADE MODEL FOR THE MONITORING OF COASTAL VESSELS USING HF SURFACE WAVE RADAR AND SHIP AUTOMATIC IDENTIFICATION SYSTEMS (AIS)

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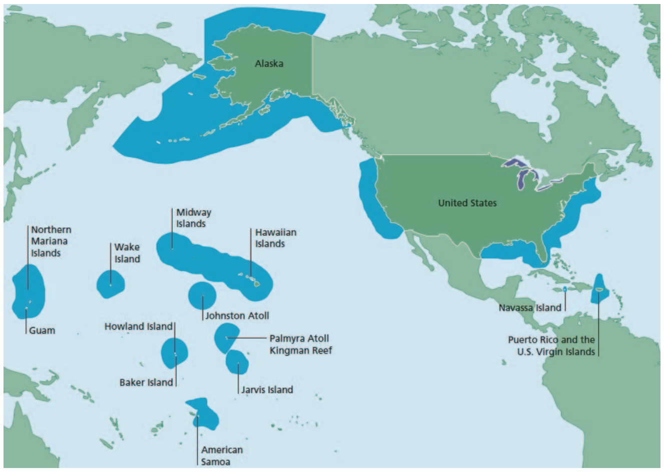
1. INTRODUCTION AND OBJECTIVE

All coastal nations have an interest in maritime domain awareness for applications in national security, coastal conservancy, fishery and stewardship of the exclusive economic zones (EEZs) along their coastlines. For example, in the United States there is a "National Plan to Achieve Maritime Domain Awareness" [1] that "lays the foundation for an effective understanding of anything associated with the maritime domain that could impact the security, safety, economy, or environment of the United States and identifying threats as early and as distant from our shores as possible." The US EEZ along coastlines, shown in dark blue at right [2], is a very large area. Monitoring such a large area using only ships, aircraft and satellite sensors would be sparse, expensive and intermittent. The problem of effective maritime domain awareness (MDA) extends globally and the U.S. government makes special efforts to aid and coordinate MDA worldwide [3]. Radio and radar techniques can provide close to continuous coverage in time and space at low cost. Our objective in this paper is to present an MDA system trade model for using HF surface wave radar and receiving stations for the automatic ship identification (AIS) beacons, carried by many vessels. We present improved models for HF and AIS performance and a system trade model that can provide the basis for optimizing the use of these powerful radio and radar techniques in the MDA effort.

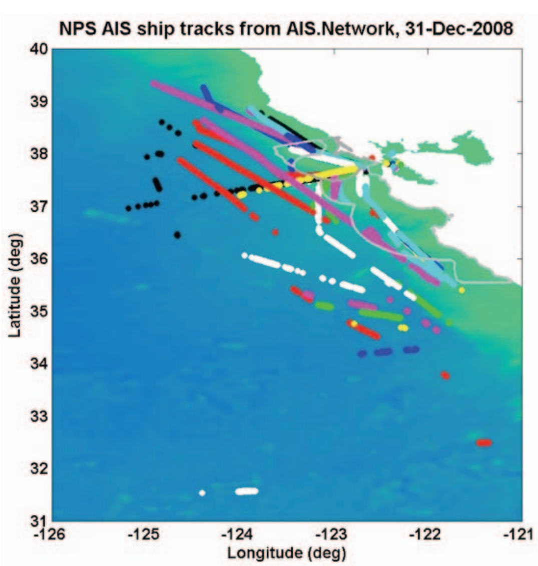


While satellite sensors can provide snapshots during overpasses and aircraft can give a continual operational picture when they are deployed, inexpensive persistent observation of both small and large vessels in coastal regions is not currently available outside of some harbors. AIS monitoring stations and HF surface wave radar are strong candidates to become components of any wide coastal area, vessel-monitoring network. A combined system has the potential to track moderate to large vessels out to distances around 200 km (much further than shore based microwave radars), a sizeable fraction of national Exclusive Economic Zones (EEZ's). In a previous paper we compared the ship detection capabilities of the Automatic Identification System AIS (installed on some ships) and coastal, surface wave HF radars [4].

In this paper we present improved models for HF and AIS performance in the coastal zone, taking into account, such characteristics as site height and location; radar type, frequency and power and vessel types of interest. The trade studies are done in terms of such quantities as probability of detection P_d and false alarm rate FAR as functions of observational parameters, such as range and frequency, as well as vessel type and size.

2. HF RADAR & AIS CAPABILITIES FOR SHIP DETECTION

The capabilities of AIS and HF surface wave radar are supplementary; each compensates for some deficiencies in the other and enhances capabilities of the other. AIS uses VHF radio interrogators and transponders to allow ships to pass information between ships and to shore stations to provide for collision avoidance and other applications. For ships that are AIS equipped and in range AIS (class A) provides a wealth of information, such as location, course and speed, rate of turn, angle of heel, pitch and roll and a unique ship identification (MMSI) number. GPS accuracy (~ 10 m) is achieved for the ship location and activity parameters. AIS is designed to cope with a large number of vessels within range, providing for automatic contention resolution between stations even in overload situations. The range of AIS is highly variable with reliable (line of sight) propagation to only about 20 km, depending on antenna height, but with intermittent propagation to large distances due to ducting, e.g. below an atmospheric temperature inversion. Elevated antennas, such as used at sites near Monterey Bay, California, observe maximum AIS range varying from 50 km on poor days to over 1000 km during very favorable conditions. Example ship tracks from AIS stations in the Monterey Bay region are shown at left above (http://www.oc.nps.edu/~cwmiller/AIS/). Satellite reception of AIS signals is being explored by the NORAIS (Norwegian Automatic Identification System) on the International Space Station in a project called the Columbus Automatic Identification System (COLAIS). A future nanosat AIS receiver AISSat-1 is under construction. These future AIS system possibilities are not included in this study.

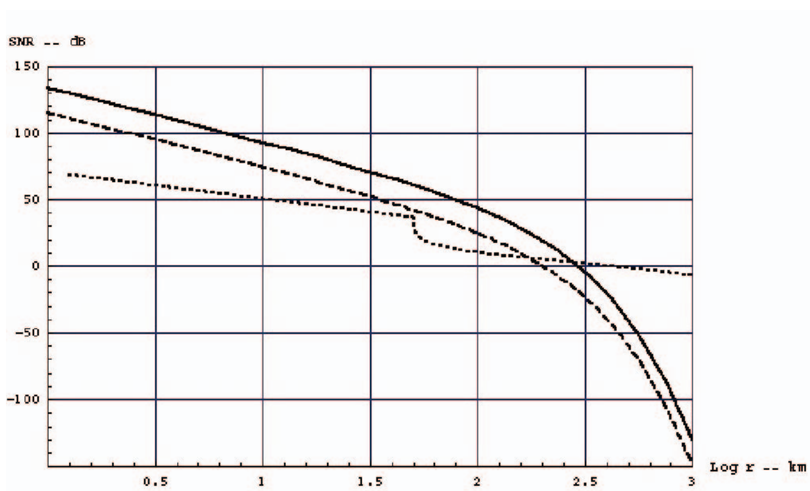


Ship-tracking capability for HF radar has not been comprehensively evaluated experimentally although much useful information exists [5]. Experimental results from Gurgle et al. in 2008 [6] and Ponsford in 2000 [7] show practical ranges as large as 200 km (50 W avg. power on 8 MHz, 260 m antenna aperture) and 350 km (3.5 kW avg power on 6 MHz, 600 m aperture) respectively. Range is dependent on antenna performance, frequency and average transmitter power. Typical information is: on location (≈ 2 km) and on radial speed (0.5 knot or better).

Comparing AIS and HF, we see relative advantages for each. AIS provides superior information, but is a cooperative system that is not carried by all ships. Most vessels over 65 ft in length or 300 gross tons on international voyages or in Vessel Traffic System area are required to carry AIS. Thus, larger ships generally have AIS, but many smaller vessels do not. HF radar is able to detect most ships over a period of time, but missed detections do occur for a variety of reasons [5]. Gurgle shows a comparison of HF and AIS in which some ships are detected by both AIS and HF radar, but some are detected only by AIS or only by HF [6]. Full aperture HF systems require extended coastal real estate, while AIS is very compact. Compact HF systems, e.g. Codar SeaSonde, also have very useful ship detection capability.

3. HF RADAR AND AIS SYSTEM TRADE MODEL

A system trade model computes the performance of a system according to a figure of merit as a function of the system design parameters so that designs can be evaluated and a practical system optimized for best performance. In this model our figures of merit are probability of detection P_d and false alarm rate FAR as functions of observational and environmental parameters. In addition a trade model has predictive capability for systems already in place. An example of model output is shown at right. In this example the signal to noise ratios (SNRs) for both AIS and HF radar are shown as functions of range between observing station and vessel. For this example the AIS receiving station has an antenna height of 75 m and an AIS antenna height of 15 m aboard a ship. SNR in dB is plotted vs. log of range in km (log r – km) for HF radar and AIS ship monitoring. The HF radar results are shown for a large ship (10,000 tons) with a solid line and a small ship (120 tons) with a dashed line. AIS receiver results are shown by the dotted line. The intermittent VHF duct is assumed present in this



example and produces the propagation characteristics that appear for ranges longer than about 50 km. SNR can be translated into the P_d and FAR figures of merit for the system trade model.

4. CONCLUSIONS

We conclude that AIS and HF radar are complementary and that a combined AIS/HF system has very significant capability in terms of cost and effectiveness. Performance increases with increasing vessel size, site height and proximity to the coast as well as increasing radar power and wavelength. AIS performance is impacted by ducting probability that is a function of atmospheric conditions. Both AIS and HF are limited by radio background noise and occasionally interference, particularly near AIS and HF observation sites. Future improvements in the system trade model could be made by better understanding of the modeling physics, especially the AIS ducting process, and more experimental evidence that characterizes the systems involved. Pilot studies using existing AIS observation stations and HF radar installations would be very useful in providing the experimental data needed for model improvement.

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