Canada's 3rd Generation High Frequency Surface Wave Radar for Persistent Surveillance of the 200 Nautical Mile EEZ

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Abstract

This paper reviews the requirements and options for providing effective Maritime Domain Awareness (MDA) from the shoreline out to, and beyond, the 200 nm Exclusive Economic Zone (EEZ). It is shown that effective MDA can be accomplished by implementing a Decision Support System (DSS) system based on a collaborative, layered approach. The MDA system takes advantage of the ability to provide wide-area persistent surveillance by new and emerging sensors such as High Frequency Surface Wave Radar (HFSWR) and Space-based interception of Automatic Identification broadcasts.

A value proposition is presented for the usefulness of different sensor and data sources, and their combinations, based on specific mission requirements. A focus is placed on the value of real-time, persistent surveillance of the EEZ using HFSWR in association with other sensor and data sources. It is shown that when associated within the MDA system anomalous or unusual vessel behavior can be identified and an appropriately response taken.

Key to providing persistent MDA is Canada's 3rd Generation HFSWR. This radar has evolved after more than 25 years of collaborative development between Defence R&D Canada and Raytheon Canada. The radar is a technology refresh of the highly successful SWR503 radar that is operationally deployed in Europe and Asia. The radar is specifically designed to be incorporated in a network of radars to form the foundation layer of a MDA System that provides enforcement agencies with real-time persistent surveillance out to and beyond the EEZ.

Options for Coastal Maritime Domain Awareness

Effective surveillance is a key discriminator in determining how well a country addresses the responsibilities and obligations implicit in the establishment of an EEZ. Today surveillance is primarily archived using a combination of self-reporting systems, patrols, and space-based reconnaissance.

Self-reporting systems include the International Maritime Organization (IMO) mandated collision avoidance, Automatic Identification System (AIS) as well as the IMO's Long Range Identification and Tracking (LRIT) system that tracks vessels engaged in international trade. Other self-reporting systems include various local fishing vessel monitoring systems. These systems have the common feature of reporting the whereabouts of collaborative vessels but do not address those vessels not required to self-report or wishing their whereabouts to remain unknown. These non-collaborative vessels must be tracked by radar. Examples of typical radar types that are available for MDA are presented in Figure 1. Persistent surveillance requires fixed radar installations whereas reconnaissance uses platform mounted radars and in general are most effective when directed to known areas of interest.

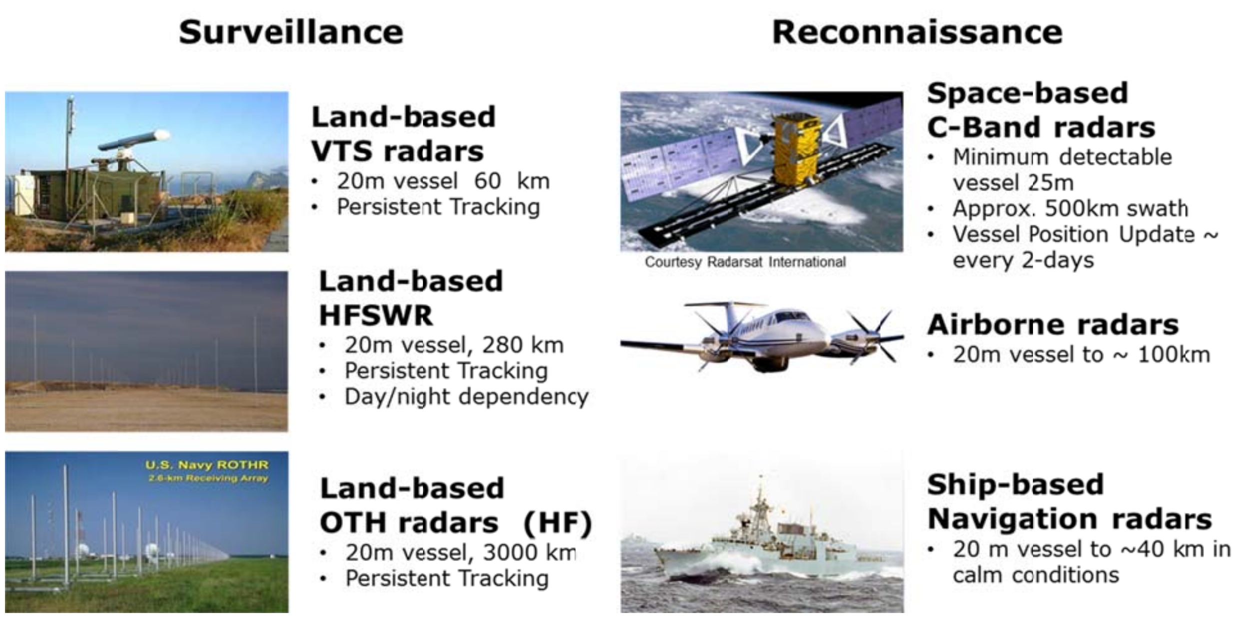

Figure 1 Radars for Monitoring Non Collaborative Vessels

Of interest to this paper is the unique capability of HFSWR for providing persistent surveillance of a nation's EEZ.

High Frequency Surface Wave Radar (HFSWR)

HFSWR systems fall into two broad categories:

1) *<u>Systems designed for coastal monitoring of surface currents and sea state conditions.</u>* These systems as characterized as radiating low power signals and typically use compact low gain antenna arrays and operate in the 5 to 30 MHz range. For coastal monitoring of surface currents and sea state conditions, system availability is not a critical factor. Therefore these system have relatively simple

signal processing capabilities and in general are not required to mitigate against the adverse effects of interference from other users of the spectrum as well as electrical noises and clutter. These systems can be configured to track larger vessels in relatively benign environments.

2) *Systems designed specifically for long-range vessel tracking.* These systems as characterized as radiating a high power signal and operate within the 3 to 5 MHz portion of the HF band where propagation losses are minimal. Spectrum availability, particularly at night, is limited by the presence of unwanted interference and clutter. To detect smaller vessels the radars employ large directive receive arrays and are required to maintain very high availability. Consequently these radars are significantly more complex than their ocean-remote sensing counterparts and incorporate advanced signal processing techniques to enable reliable operation in complex RF environments.

A detailed review of HFSWR for detection and tracking of surface vessels is presented in [1].

Canada's 3rd Generation HFSWR

HFSWR is an enabling technology that has been shown to provide real-time persistent surveillance of surface activity throughout the EEZ. Operational concerns related to the use of this class of radar has focused on two primary areas: operation as a non-allocated user within the congested HF-band and the real-estate requirements for coastal installations.

The objective of a cognitive radar is to utilize knowledge obtained either by sensing the local environment or from trusted third party sources to maximize the probability of track initiation whilst minimizing the probability of false or otherwise erroneous tracks. As illustrated Figure 2, the 3rd Generation HFSWR is based on a cognitive architecture and consists of three major sub-systems; an Adaptive HFSWR, an Optimizer and data from trusted third party sources. For the demonstration system these auxiliary data sources consisted of a Wide Band Spectrum Monitoring System and a Data Fusion Processor that associated HF Radar derived surface tracks with known shipping in the area obtained primarily from Space-based interception of AIS reports. The data was combined to provide a comprehensive real-time overview of surface vessel activity [2].

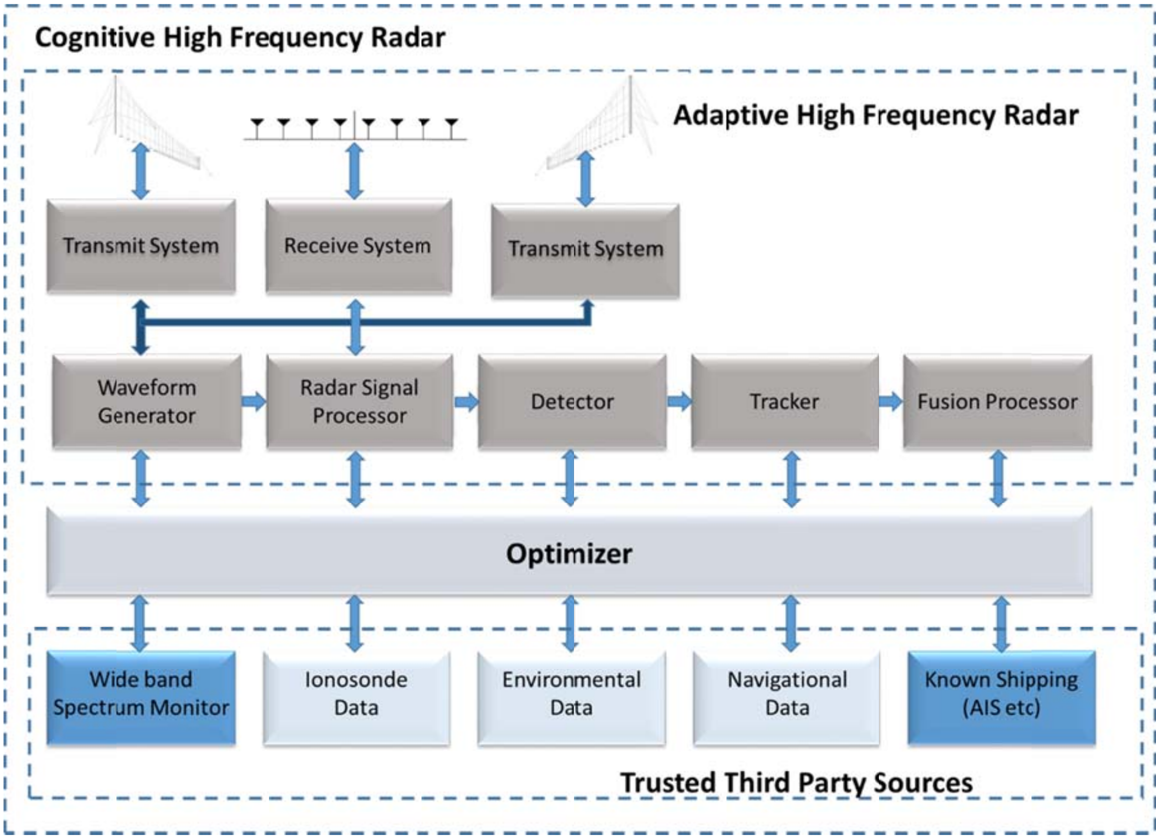

Figure 2 Key Components of the Cognitive 3rd Generation HFSWR System

Canada's 3rd Generation system occupies a single site with co-located transmit and receive sub-systems. Virtual Aperture Array (VAA) technology results in a radar site requiring half the ocean frontage compared to competing systems offering similar performance [3]. Cognitive Sense-and-Adapt technology and Dynamic Spectrum Management ensure robust and resilient operation in the highly congested HF band. Dynamic Spectrum Access (DSA) enables the system to simultaneously operate on two frequencies on a Non-Interference and Non-Protected Basis without impacting other spectrum users. DSA is also the primary line of defence against performance degradation by unwanted signals that attempt to jam the radar [4].

Sense-and-Adapt techniques ensure that the system instantaneously switches to a new vacant channel on detection of an unwanted or jamming signal. Adaptive signal processing techniques mitigate against electrical noise, interference and clutter [5]. Sense-and-Adapt techniques applied at the Detector and Tracker stages maximize the probability of target tracking whilst minimizing the probability of false or otherwise erroneous tracks [6, 7, 8].

The 3rd Generation HFSWR system has been optimized for long-range detection of vessels but also includes the optional capability to track larger aircraft at all altitudes. The system outputs tracks of vessels and aircraft. It is designed for seamless integration with other customer deployed C2 systems.

In summary, the 3rd Generation HFSWR is a proven technology that offers unsurpassed persistent, real-time surveillance of the EEZ such that patrol and response assists can be vectored to specific targets of interest, enabling interceptions well outside territorial waters. In this manner, HFSWR systems have been proven to be a significant force multiplier for customers by allowing other mobile systems to be optimally deployed and tasked.

Key Features

The radar operates in a monostatic mode and occupies a single site and is offered in both a standard and compact installation. The standard installation requires no more than 700-meters of ocean frontage. The compact installation requires no more than 350-meters of ocean frontage.

Radar coverage area extends from a minimum range of no more than 40 kilometers (km) to an instrumented range of at least 400 km over a sector of no less than 120 degrees (deg). The radar simultaneously tracks vessels of different sizes to ranges as depicted in Table 1.

Table 1 Typical range performance as a function of vessel type, sea state and time of day

(instrumented Range 40 – 400 km)

Vessel Type			RCS FS dB m^2	Sea State 3 (day/night)	Sea State 5 (day/night)	Sea State 7 (day/night
Class 1: Mid-Shore mechanical Fishing Vessels			15-20	230/210	-	-
Class2: Regional Vessels (Tugs, Offshore Fishing vessels, Barges, etc)			20-25	300/220	180/120	140/120
Class 3: Local Coastal /Cabotage vessels			25-35	370/260	300/220	180/150
Class 4: Large coastal and ocean going vessels,			>35	370/260	370/260	370/260

All ranges in kilometers, RCS are Free Space and Aspect Angle Averaged

The radar operates with frequency diversity that enables the system to be simultaneously optimized for detecting large targets at long range and smaller targets at nearer ranges. The radar operates on a Non-Interference and Non-Protected Basis with respect to allocated users and automatically selects the best frequency and bandwidth of operation based upon the local spectral measurements. While operating at a specific frequency and bandwidth the radar detects the presence of an external user within the bandwidth of operation and automatically switches to a different frequency of operation and bandwidth. If no channels are available the radar can be configurable to either operate at a pre-defined default frequency and bandwidth or cease transmission until channels become available. Filters are included such that under no circumstances will the radar operate on specified users defined prohibited frequency bands.

The Radar is designed to simultaneously track up to 500 targets with each track assigned a unique identification number. Track-updates under normal conditions are typically in the order of once per minute.

System Performance

Figure 3 demonstrates the capability of the radar to continuously track a highly manoeuvering vessel over an extended period of time. The MV Strait Explorer, is a category 2 target that was continuously tracked during acceptance trials. The trials were undertaken during Gale Force conditions and lasted for greater than 24 hours. During the trials the vessel undertook a number of extreme manoeuvers without the radar losing track. The radar operated in a frequency agile mode with the maximum continuous time on any given frequency being set to 20 minutes. The vessel was tracked to maximum day and night ranges.

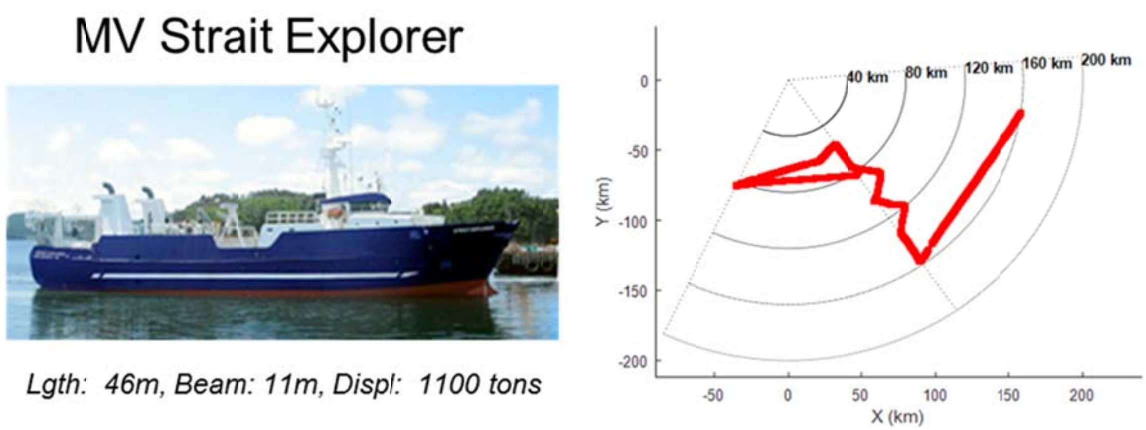

Figure 3 System Acceptance Testing: Test Vessel continuously tracked for ~ 27 hours through extreme maneuvers, including stop-go, with 2058 associated plots (approx 1 min update rate)

The ability of the radar to monitor all vessels operating with the 200 nautical mile EEZ is demonstrated in Figure 4. This example demonstrates the radars ability to detect and track small fishing vessels as represented by the two red tracks. It also illustrates the advantages of associating the radar track data with self-reporting data obtained from the interception of broadcasts by space-based assets of AIS the IMO mandated collision avoidance system. In the example the blue lines are radar tracks, the green diamonds are AIS derived vessel reports. It can be observed that a number of radar derived vessel tracks do not have associated AIS reports and are therefore unknown or “dark targets”.

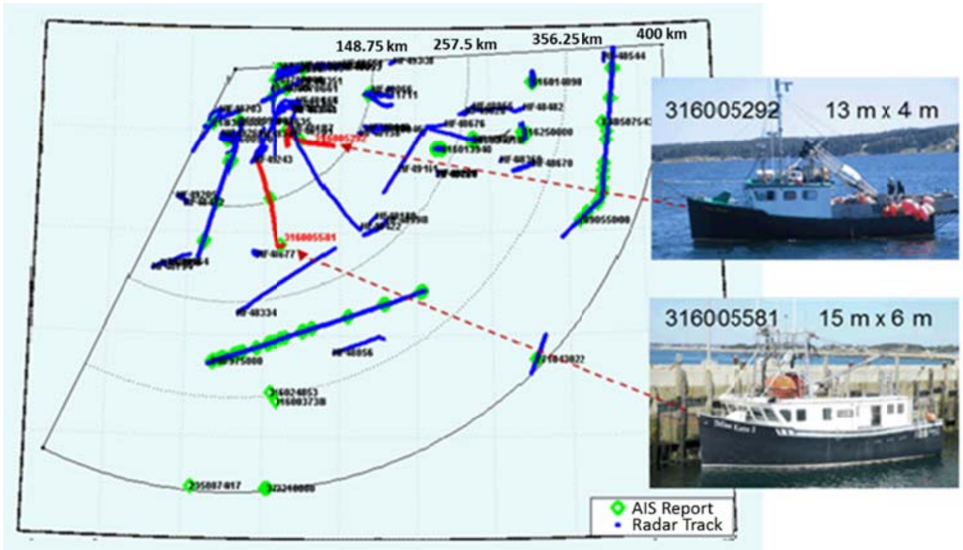

Figure 4: Example of the HFSWR Radar Track demonstrating the ability to track small fishing vessels (red lines) and general HFSWR tracks (blue lines) overlayed with Spacebased Interception of AIS data (green diamonds) illusutrating that a number of vessels are not broadcasting AIS messages and represent targets of interest.

Summary

Canada's 3rd Generation system occupies a single site with co-located transmit and receive sub-systems. Virtual Aperture Array (VAA) technology results in a radar site requiring half the ocean frontage compared to competing systems offering similar performance. Cognitive Sense-and-Adapt technology and Dynamic Spectrum Management ensure robust and resilient operation in the highly congested HF band. Dynamic Spectrum Access (DSA) enables the system to simultaneously operate on two frequencies on a Non-Interference and Non-Protected Basis without impacting other spectrum users. DSA is also the primary line of defence against performance degradation by unwanted signals that are attempting to jam the radar.

It has been shown that HFSWR is a proven technology that offers unsurpassed persistent, real-time surveillance of the EEZ such that patrol and response assists can be vectored to specific targets of interest, enabling interceptions well outside territorial waters. In this manner, HFSWR systems have been proven to be a significant force multiplier for customers by allowing other mobile systems to be optimally deployed and tasked.

References

[1] A.M.. Ponsford and J. Wang *A Review of High Frequency Surface Wave Radar for Detection and Tracking of Ships,* Special Issue on Sky- and Ground-wave High Frequency (HF) Radars: Challenges in Modelling, Simulation and Application, Turkey Journal of Electrical Engineering & Computer Science, Vol.18, No.3, 2010.

[2] P. Moo, A.M. Ponsford, D. DiFilippo, R. McKerracher, N. Kashyap and Y. Allard, *Canada’s Third Generation High Frequency Surface Wave Radar System*, Journal of Ocean Technology - Special Issue on Maritime Domain Awareness, Vol. 10, No. 2, 2015.

[3] US Patent, US20140197984 A1, *A System and Method for generating a Virtual Aperture Array Extension*, J. Wang, E. Wang, R. McKerracher and A.M. Ponsford, Jan 2017.

[4] R. McKerracher, P. Moo and A.M. Ponsford, *Spectrum Utilization: Sense and Adapt: Operation on a Non-Interference and Non-Protected Basis,* To be published in the IEEE Special Issue on HF Radar of the Aerospace and Electronics System Magazine, 2017.

[5] U.S. Provisional Application 62/349,798*, Impulse Noise Detection And Removal For Radar And Communication Systems*, R. McKerracher and A.M. Ponsford, June 2016.

[6] E. Wang, J. Wang and A.M. Ponsford, *An Adaptive Hierarchal CFAR for Optimal Target Detection in Mixed Clutter Environments*, IEEE Radar Conference, Kansas City, May 2011.

[7] US Patent 9,157,992, *Knowledge Aided Detector*, E. Wang, J. Wang and A.M. Ponsford, Raytheon Canada Limited, Oct 2015.

[8] US Patent 7,626,535, *A Track Quality Based Multi-target Tracker*, Z. Ding, A. Sinha, T. Kirubarajan, M. Farooq, Raytheon Canada Limited, Dec 2009.