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The Technological Challenges of Maritime Information Warfare

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***Abstract* — Maritime Information Warfare (MIW) provides a unifying concept for the integration, within naval operations, of information; command and control (C2); intelligence, surveillance and reconnaissance (ISR); electronic warfare (EW); and cyber systems. MIW leverages the plethora of socio-technical networks, sensors and information sources (e.g. terrestrial, space based, open sources) to support the development of a multi-layered, multi-domain operational maritime picture. However, modern navies are relentlessly challenged by the rapid changes in communications; sensors; signal processing; information management; and, imaging technologies. To illustrate the MIW R&D challenges and opportunities facing the Royal Canadian Navy (RCN), this presentation highlights some of the concepts and technologies being explored within the current research program. This will include new sensors and information management technologies being developed within Defence R&D Canada. This research will be exploited to ensure optimal operational and tactical level decisions for both independent and coalition maritime operations in domestic and global theatres; and, support Command's ability to maintain both effective and technologically relevant Command Decision Support and Control.**

***Index Terms* — Maritime Information Warfare, Radar, Command and Control, C4ISR.**

I. INTRODUCTION

The operational and tactical challenges of the maritime environment are unique and highly demanding, especially as they pertain to naval operations. Similarly, the scientific and engineering solutions to these challenges are among the most scientifically and technologically interesting in defence science, requiring multi-disciplinary methods and considerable creativity. As a result, navies are intensely science and technology (S&T) focused, with naval epochs defined by changing technologies and their exploitation. One of the key defining aspects of today's naval epoch is the focus on information supremacy, driven by advances in communications, sensors, networks and the novel exploitation of the electromagnetic (EM) spectrum writ large.

The Royal Canadian Navy (RCN) arose in 1910 at the end of one such technology boundary. Today's RCN and the defence scientists in Defence R&D Canada (DRDC) who support it, are exploring the impact of the changing information technology environment on naval operations. As a means to highlight these developments, and the S&T that underlies them, we will outline in the next section the current challenges faced by the RCN in the context of Maritime Information Warfare (MIW) and the related challenges of Maritime Domain Awareness (MDA).

II. THE CANADIAN MARITIME CONTEXT

Understanding who or what is operating in waters of interest is the central challenge of MDA. Domestically, MDA is, and will continue to be, a critical component of the Canadian National Security Strategy as the cornerstone for all other maritime security activities [1]. The operational and C4ISR (Command, Control, Communications, Computers, Intelligence, Surveillance and Reconnaissance) challenges of having the world's longest coastline (202,080 km), and the emergence of Canada's arctic (an area larger than Europe) as an essential operational area, should not be underestimated. At the same time, the costs of operating in the arctic and maintaining situational awareness across the vast expanse of Canadian territory and waters are considerable. The critical maritime S&T challenge is how to leverage new technologies to provide appropriate wide-area C4ISR in support of Canadian sovereignty and maritime operations, at a realistic cost. Fig.1 provides an overview of the domestic maritime areas of responsibly (AOR).

Fig. 1. Canadian Domestic Maritime Areas of Responsibility.

As part of the international community, Canada has a role in defending the global system both at sea and from the sea. However, as a middle power, this expeditionary capability presents its own technological, affordability, interoperability, readiness, and sustainability difficulties. In particular, it is non-trivial to conduct or contribute to naval operations around the world and to maintain global maritime situational awareness necessary to support this ambition. Even domestic defence and security needs necessitate global situational awareness, given the nature of global commerce and associated maritime inter-relationships. With 90% of global trade, per volume, traveling by sea, and the shear number of vessels operating at sea on any given day, situational awareness and protection of the global commons is important not only for Canada but for all nations (Fig. 2.).

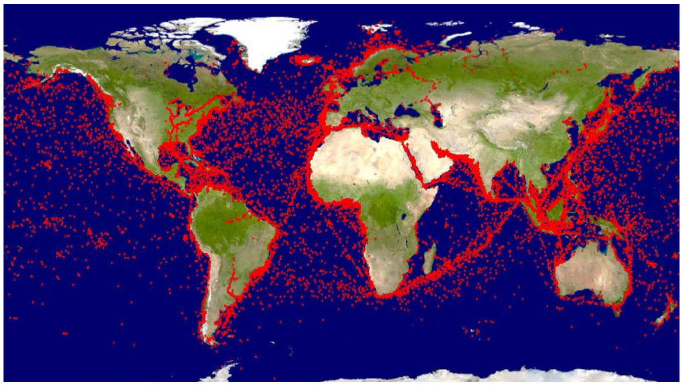

Fig. 2. Global vessel traffic taken over a 24-hour period beginning 8-Nov-2011 13:00:00 with 29,480 unique vessels identified [2].

Finally, the Royal Canadian Navy (RCN) is taking up the challenge of maintaining and building Canada's future Navy. The fleet of the future is expected to be broadly balanced and combat capable, fully meeting the expeditionary and domestic missions set for the Canadian Armed Forces (CAF) by the Government of Canada (GoC), including those pertaining to the arctic. To meet this challenge, the RCN is in the middle of the largest recapitalization of the fleet in history, as part of the $38.6 billion National Shipbuilding Procurement Strategy (NSPS). Maritime sensors, networks and information systems are essential enabling capabilities for these vessels, as they will ensure the operational effectiveness and technological readiness of the RCN.

II. MARITIME INFORMATION WARFARE (MIW)

Military operations are conducted simultaneously in three domains – physical, information and human. Warfare in the information domain seeks to influence the sequence of events, information available, and interpretation of intelligence within a doctrinal and cultural context. Thus at its core, information warfare is one of narrative dominance. Information warfare, of one kind or another, has been a fundamental element of warfare going back at least to the works of Sun Tzu; however, the nature of that battle space has changed dramatically over the last 20 years.

While easy to understand at the broad conceptual level, the doctrine, concepts and theory of information warfare are still under-developed and complicated by its multi-disciplinary and cross warfare area nature, as well as the ever-evolving technological environment. New sensors, as well as processing, communication and decision systems, provide novel ways of engaging in information space, and present new vulnerabilities. Networks of nodes (storage, people, computers, libraries, etc.) and links between these nodes span the information battlespace, with information flowing in a complicated and interdepended fashion.

The application of information warfare to maritime operations adds the additional complications inherit in operations at sea and the vast spaces involved. MIW is characterized by operations in the global commons, be these international waters or the EM spectrum, and the resulting union of computer information systems; command & control (C2) systems; intelligence, surveillance and reconnaissance (ISR) sensors; electronic warfare (EW); and, cyber security.

In the Canadian context, MIW seeks to enhance the effectiveness of the RCN command team by improving information management techniques and promoting greater situational awareness through improved intelligence gathering, surveillance analysis, and sensor integration. Maritime Domain Awareness (MDA), in this context, is a critical facet of MIW.

III. MIW RESEARCH

In Canada, MIW defence research in support of RCN domestic and global operations focuses on C4ISR concept development and experimentation (CDE); technologies and ideas to ensure coordinated kinetic and non-kinetic action (Joint Fires); new ISR sensors; information sharing and exploitation; and, C2 decision support. To better illustrate these MIW R&D challenges and opportunities and place this in the context of evolving EM technologies, this section will consider a small sampling of concepts and technologies under active investigation within the RCN defence research program.

A. Ground-Based High-Frequency Surface Wave Radar (HFSWR)

Given the length of the Canadian coastline, persistent and continuous surveillance of Canadian coastal waters and air space out to the edge of the 200 nautical mile (nm) Exclusive Economic Zone (EEZ) presents a unique technological challenge. Coastal MDA is possible through space-based sensors, unmanned air vehicles (UAVs) and Maritime patrol aircraft; however, they come at a high cost and lack persistence.

Over the last 10 to 15 years, the Automated Identification System (AIS), a short-range VHF system, and satellite borne receivers, have made tracking and identification significantly easier. As a result, the majority of large oceans going commercial traffic is tracked while approaching or operating in Canadian territorial waters [3]. Nevertheless, such self-reporting requirements do not apply to military vessels, small craft or commercial fishing vessels. Further, such systems may be disabled, hacked, spoofed or simply fail. As such, independent surveillance, tracking and identification of these uncooperative or "dark targets" within Canada's maritime approaches is a security and defence imperative.

Since 1984, Canada has explored the use of High Frequency (HF) radar as the most viable sensor technology available to address the defence and security problem of persistent coastal MDA [3]. Ground-based High-Frequency Surface Wave Radars (HFSWR) transmit and receive HF waves, which travel along the curved ocean surface well beyond the line-of-sight. Working with Raytheon Canada, two SWR-503 HFSWR systems were developed, installed and integrated into Canadian Maritime Security Operations (Fig. 3). These single frequency systems operated successfully until 2007, when they were decommissioned due to concerns of potential interference with civilian HF communications [3].

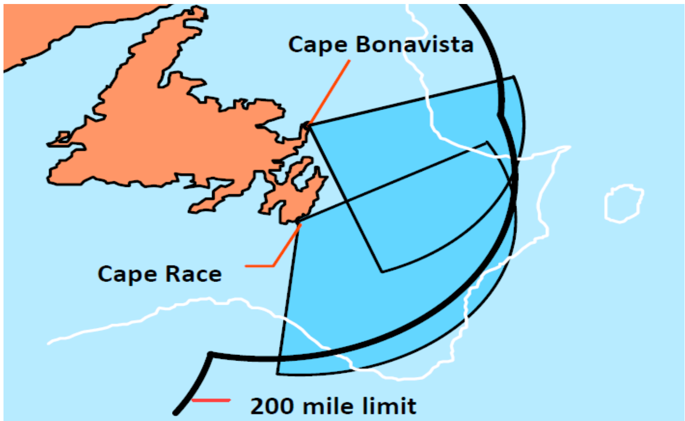

Fig. 3. HFSWR (2003-2007) at Cape Bonavista and Cape Race Newfoundland.

In 2011, development began on a mono-static pulse Doppler "3rd Generation" HFSWR system near Halifax, Nova Scotia (Fig. 4.), with co-located transmit and receive sites. The objective of the *Persistent Active Surveillance of the EEZ (PASE)* project was to demonstrate, through an experimental HFSWR, 24/7 MDA operations, reduced equipment and operational costs, and strict non-interference with commercial HF communications [3].

Fig. 4. PASE HFSWR System at Hartlen Point, Halifax, Nova Scotia.

The PASE HFSWR operates on two independent frequencies in the HF band (3-20 MHz) and employs a number of advances in radar electronics, HF power amplification, object detection, tracking and data fusion. The most noteworthy advance was the development of a Pro-active Remote Intelligent Spectrum Management System (PRISM). Employing dynamic channel occupancy analysis, with automatic frequency shifting, the PASE HFSWR dynamically adapts the carrier bandwidth to the available spectrum [3].

In 2015, the PASE HFSWR system successfully demonstrated its ability to conduct 24/7 operations in a highly congested HF environment. The system provided high quality and high confidence tracks within a 200 nm maximum range and over a large group of target classes and sea conditions [3].

From a technology perspective, a valuable lesson learned from PASE and earlier HFSWR research, is that MIW systems must consider and actively adjust to the increasingly congested EM environment. The bandwidth for unique military applications is decreasing as more and more spectrum is allocated for commercial use. Intelligent, adaptive and agile EM spectrum management, like that taken within the PASE project to enable shared spectrum with other dynamic users, will be no longer be an option, but rather a requirement for communication and radar systems. Given such a future EM battlespace, the US Defence Advanced Research Program Agency (DARPA) has been funding similar research activities for spectrum management in congested environments [4].

B. RadarSat Constellation Mission

HFSWR provides a good technological solution to the problem of coastal MDA, but global MDA and the expeditionary requirements of the RCN require worldwide surveillance architectures, as well as the ability to track and identify vessels of interest. Once again, maritime patrol aircraft and UAVs provide some capability, but lack the truly global coverage necessary. It is not enough to know who is operating at sea, but history and operational context may also prove to be important. Further, surveillance in support of RCN operations abroad requires a global system.

In order to achieve such capabilities, space based assets provide the best possible option. AIS provide a good example of a low cost satellite enabled global solution. Commercial firms provide AIS position data with an update frequency measured in minutes. However, for MDA an MIW system requires sophisticated sensors, processing and analysis, in order to focus on objects of interest and non-cooperative dark targets.

Canada has been a leader in the development of space based synthetic aperture radars for MDA, primarily through the development with MacDonald Dettwiller and Associates over the last 15 years of the RADARSAT-1 and RADARSAT-2 radar satellites. To leverage the nearly $455-Million-dollar GoC investment in RADARSAT-2 the Department of National Defence initiated in 2005 the Polar Epsilon project, to provide enhanced space based wide-area surveillance.

RADARSAT-2 is a sun-synchronous polar orbiting satellite, with a period of approximately 100 minutes, employing a Synthetic Aperture Radar (SAR). Optimized for wide-area surveillance (ScanSAR Narrow mode with a pixel resolution of 25m by 25m) imagery is collected over ocean swaths hundreds of km wide and up to a thousand km long (Fig. 4). Such expanses are too large for traditional imagery interpretation methods. To deal with the interpretation problem, a suite of software tools (OceanSuite) was developed by DRDC to exploit magnitude format, single polarization imagery generated by RADARSAT-2 [5]. This system provides near real-time ship detection, including position, probable course and estimated length. Due to collection, communication and processing delays, effective observation to dissemination times range from 8 – 24 hours [5].

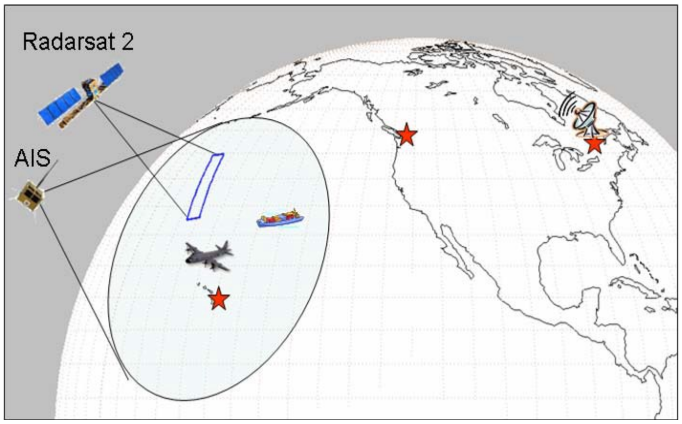

Figure 4. RADARSAT-2 and AIS satellites [5].

The success of RADARSAT-2, and the Polar Epsilon project, has spawned a GoC follow on activity – the RADARSAT Constellation Mission (RCM). After an expected 2018 launch, three solar powered polar orbiting small satellites will be launched with a period of 96 minutes. Employing both SAR and AIS payloads, the RCM will provide surveillance coverage of 90% of the world's surface. Among its many missions, RCM will support ecosystem monitoring and disaster management, as well as providing a major increase in global maritime surveillance capabilities.

The successes of RADARSAT, Polar Epsilon and current MDA research in support of RCM, have highlighted a number of technical challenges for future missions. In particular, new on-board capabilities will run into communication bandwidth limits. These in turn will drive ground based and on-orbit processing capabilities, including the use of quantum-optimized algorithms for big data and the use of increased on-satellite processing and track generation.

C. Cooperative Missile and Air Defence (C3MAAD)

While MDA is a necessary component of a robust and capable MIW system, MDA in and of itself is by no means sufficient to support complex military operations. As part of RCN domestic and expeditionary operations, it will be increasingly necessary to manage immense volumes of data, fuse this information into a sensible narrative, and provide a C2 environment optimized for decision making in complex, complicated, high-tempo and high-risk operational environments. Developing core technologies to address the avalanche of data and integration into C2 systems is essential for the new fleet [6].

To ensure the technical and operational effectiveness of the RCN, DRDC is exploring optimal battle management concepts and technologies. One such Canadian defence project - Coordination Concepts for Cooperative Missile and Air Defense (C3MADD) - seeks to develop, demonstrate and evaluate concepts and technologies supporting command teams in the conduct of Area Air Defence (AAD) and Force Anti-Ship Missile Defence (FASMD).

Naval battle management systems must contend with a number of serious technical and operational challenges. These include:

1) Rapidly evolving and agile threat systems, including hypersonic weapon systems;
2) Operations in cluttered, confused and congested environments such the littorals;
3) Coordinated and effective action and joint fires, amongst dispersed and diverse ships within the task group through cooperative engagement and distributed sensing; and
4) Rapid information exchange and decision making in a high-risk low latency network centric operational environment.

These are complex and complicated issues, and most navies are still at the stage of optimizing single-ship battle management capabilities.

C3MADD is a collaborative effort between DRDC, the RCN and Canadian industry to develop and assess the effectiveness of new multi-node air defence C2 algorithms, shared sensor information and response tactics amongst a task group in order to improve response times and ultimately increase ship survivability. Command decision aids are being developed with cognitive support for decision making during FASMD and AAD operations. Further, comprehensive evaluation methods and metrics have been designed to permit the validation and assessment of the performance and operational effectiveness of new technologies, concepts of operations, automation, decision aides and architectures.

III. THE FUTURE TECHNOLOGICAL CHALLENGES AND THE INFORMATION ENVIRONMENT

While the previous section presented some examples of MIW research and future technical challenges, additional evolutionary and transformative S&T developments are expected to fundamentally change the information battle space. Among these S&T drivers are increased technological affordability, cloud & quantum computing, the globalisation of S&T, additive manufacturing, socio-technical networks, increased use of space, extension of the human frontier, unseen technological surprises and evolving sensing & analysis technologies [7]. As a whole, these developments will have profound implications for future military operations and technology based capabilities.

In this context, it is expected that advanced manufacturing, machine intelligence and the globalisation of S&T will together drive the development and proliferation of unmanned or autonomous vehicles. As ISR collection platforms, utilizing a plethora of old and novel technologies, these systems will become nearly ubiquitous over the coming decades. The ability to create cheap on-demand systems and sensors via advanced manufacturing methods, capable of fully autonomous and self-organizing behaviors (based on increased machine intelligence and fully network enabled) will drastically increase the effectiveness of individual sensors and platforms, while raising significant issues around their use by future adversaries. Widespread utilization of advanced manufacturing (employing additive manufacturing, or 3D printing) and intelligent systems is also expected to drive significant changes in signature management and the development of countermeasures through the use of new designs and materials. Also, with the barriers to technology insertion (i.e. access, cost and speed) removed, additive manufacturing will enable future threats and vulnerabilities (e.g. cyber and material assurance) with the potential to level the technological playing field between state and non-state actors [7].

The growing need for increased spatial and temporal precision in military operations will increase the reliance of navies on space based or space enabled systems for MDA. The availability of new sensors, nano-satellites, increased satellite on-board processing and improvements in cloud and quantum computing, will yield vast improvements to our ability to maintain situational awareness. In particular, such systems-of-systems will provide accurate, timely and persistent situational awareness of the maritime approaches and global waters, as well as increased arctic intelligence and the ability to track "dark targets". However, reliance on space systems may also lead to greater vulnerability to disruption and degradation.

Finally, "the human frontier" will progress along cognitive, psychosocial, physiological and physical axes. Rapid advances in human-systems integration, big data analytics and increased machine intelligence will help tame the data-to-decision problem presented by the plethora of new sensors and technologies. Conversely, fundamental human physical, social and cognitive constraints will continue to limit our ability to absorb, integrate and employ new technologies. Nevertheless, building systems and networks optimized for rapid decision making through a better understanding of the human factor and human-technical interfaces will lead to more effective and adaptable MIW systems.

VII. CONCLUSION

If history is to be a guide, the impact of S&T trends on future MDA and MWI systems will be difficult to predict. What is clear, however, is that the success of future navies will depend not only on S&T innovation, but also on their ability to understand and adapt to this changing environment, particularly as it applies to MIW. Novel sensors, improved data processing, cooperative spectrum sharing, improved access to space and the ability to weave large quantities of data into a narrative form suitable for high risk and rapid decision making will be essential aspects of future MIW systems.

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