A Commercial Approach to Successful Persistent Radar Surveillance of Sea, Air and Land Along the Northern Border

Tim J. Nohara, P.Eng, Ph.D, *Member, IEEE*
Accipiter Radar Corporation, 40 Centre Drive, Orchard Park, NY, USA 14127.
Tel: 716-508-4432, Fax:888-393-6421 tnohara@accipiterradar.com

***Abstract* — The benefits of a commercial approach to the deployment of radar surveillance along the Great Lakes St. Lawrence Seaway System (GLSLSS) is discussed. Surveillance solutions must be multi-mission suitable, scalable, flexible, maintainable, upgradeable, interoperable, shareable, and affordable. This flexibility is fundamental to successfully leveraging tomorrow, investments made today in order to keep up with changing threats and technology. Not only can homeland security surveillance solutions benefit by leveraging commercial technologies, but non-sensitive target information, can drive significant human and commercial benefits. The paper presents a radar surveillance framework whose network architecture, COTS components, specially designed components and open interfaces are discussed. The modular nature of the framework includes software definable algorithms for acquisition of sea, air or land targets of interest, built-in integration of target information that fully scales in support of wide-area surveillance, and open interfaces in support of new, multi-mission situational awareness applications.**

***Keywords* — radar; surveillance; homeland; security; multi-mission, wide-area; border; situational awareness; COTS; affordable**

I. INTRODUCTION

Efforts have been underway since 9/11 to develop and deploy wide-area surveillance solutions along North American borders. The challenges, expense and lessons learnt in trying to build a 37 km virtual fence along the southern border with Mexico are a cause for reflection, as attention turns towards the northern border with Canada. This paper discusses the benefits of a commercial approach to the deployment of radar surveillance along the Great Lakes St. Lawrence Seaway System (GLSLSS), which includes densely populated urban/industrial centers, and a 3,700 km unmanned border running through the middle of a vast waterway extending from the Atlantic Ocean to Duluth, Minnesota.

Surveillance solutions must be mission-suitable, scalable, flexible, maintainable, upgradeable, interoperable, shareable, and affordable, taking into account complete system life cycle costs. These requirements demand the engineered leveraging of commercial-off-the-shelf (COTS) components carefully integrated with specialized hardware and software to deliver a modular and open surveillance framework upon which multi-mission, user-driven situational awareness applications can be easily developed and added over time, through low-cost upgrades.

This flexibility is fundamental to successfully leveraging tomorrow, investments made today in order to keep up with changing threats and technology. Advances in computer, communications, and GPS-based technologies over the past 20 years, together with the continuous availability of low-cost, secure, user applications that run on top of these platforms are a testament to the merits of the proposed commercial approach. Not only can homeland security surveillance solutions benefit by leveraging commercial technologies, but government investment in surveillance solutions can return to the economy a peace dividend through the provision of non-sensitive target information, which can drive significant human and commercial benefits.

The paper presents a radar surveillance framework that has been successfully tested over several years by US and Canadian government agencies at locations throughout North American including the GLSLSS. The framework's network architecture, COTS components, specially designed components and open interfaces are discussed. Framework design features that ensure robust integration of components (even under dense target environments), and end-to-end system performance and scalability will be presented. The modular nature of the framework includes flexibility in selection of platforms, transceivers, and antennas to address coverage and performance requirements, software definable algorithms for acquisition of sea, air or land targets of interest, built-in integration of target information that fully scales in support of wide-area surveillance, and open interfaces in support of new, multi-mission user applications as well as straight-forward integration with third party applications to deliver desired situational awareness toolsets. Real examples of each of these framework components including target information (from sea, air and land) and toolset examples taken from a variety of deployments are used to demonstrate compliance with each of the aforementioned requirements. In addition, the claimed benefits of this commercial approach to radar surveillance for the northern border are illustrated.

II. RADAR SURVEILLANCE FRAMEWORK

A. *Commercial Cellular Model*

Cellular networks provide an excellent example of the benefits of a commercial approach to wide-area radio communications. The radio communications problem is analogous to radar (radio detection and ranging) with the fundamental difference being that in radar, the receiver has to extract its (target) information from *reflected* RF signals; whereas in radio, the transmission and reception of information using RF signals is cooperative.

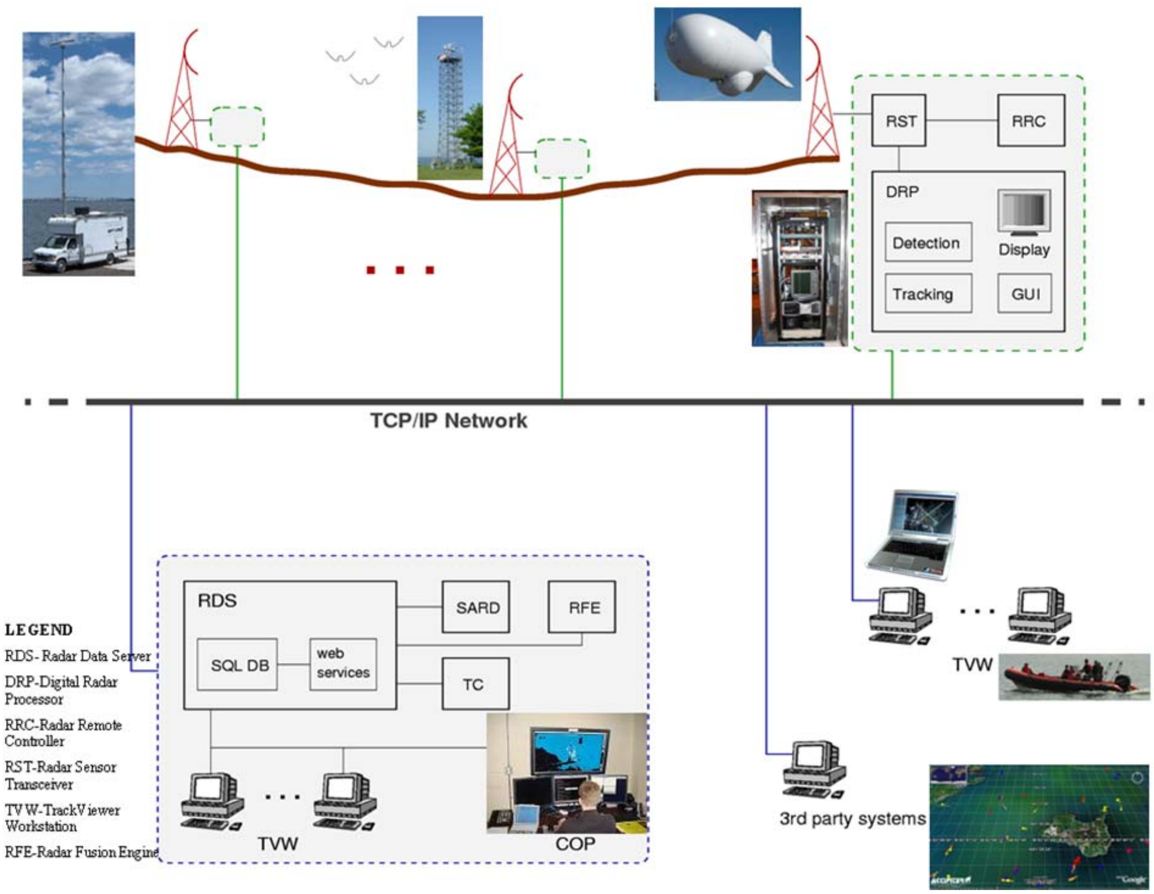

Figure 1: Wide-Area, Network-Centric Architecture

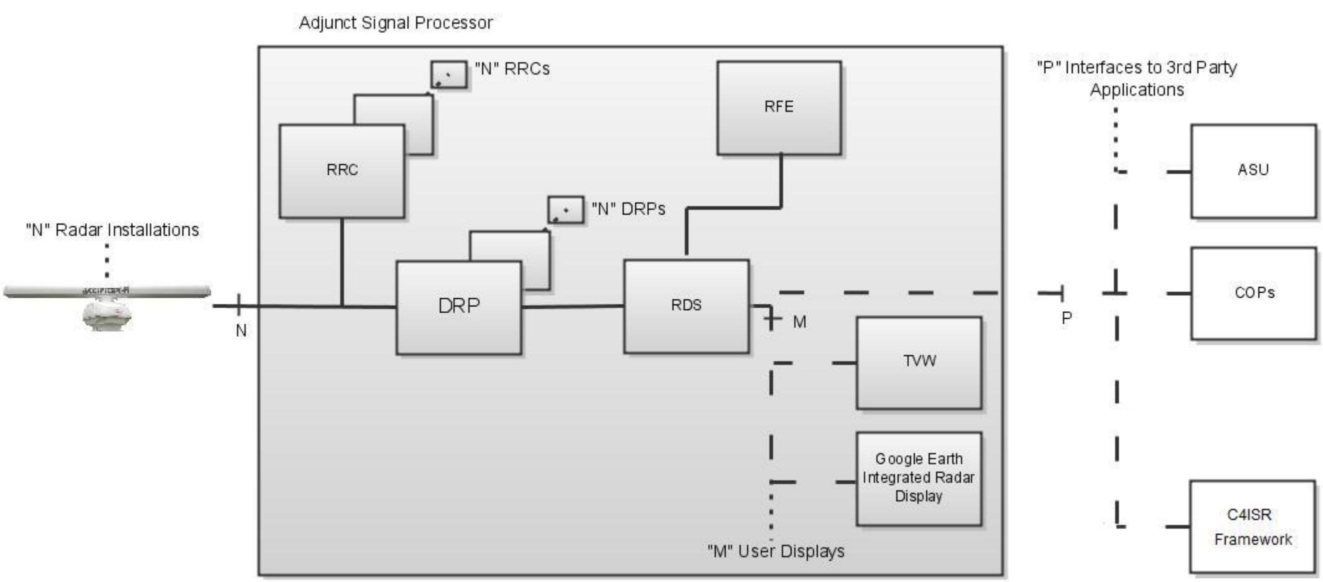

Figure 2: Adjunct Signal Processor

Cellular networks are multi-mission, scalable, flexible, maintainable, upgradeable, interoperable, shareable, and affordable; and radar networks that follow this approach (as described in the sequel) can be too. An ongoing introduction of secure, user software tools or applications that run on the network are available to users affordably, with different missions, such as communication (telephony, text messaging, email), office applications, research (web browsing, database access, etc.), as well as custom-developed, GIS-based applications for situational awareness. Government and security professionals rely on these networks demonstrating that even secure mission requirements can be satisfied using industry security protocols and standards.

Cellular networks are scalable. Rollout began with one or more cells in important urban centers, and grew to wide-area, nation-wide and even global coverage. Users roam from cell to cell transparently. Cellular networks are also interoperable and shareable. Different companies rolled out in different parts of the country, and by establishing interfacing standards, phone calls originating on one provider's sensors are routed to another's (where sensors are shared) or even to a fixed, land-line network such as the public switched telephone network (PSTN). Radar coverage can rollout in a similar manner, with radar cells first placed in critical areas, and with gaps being filled over time for wide-area coverage. With target information interface standards, information can be shared from different radar cells using different radar sensors to expand coverage. Even existing radars, such as vessel traffic services radars, ship-based radars, and other land-based radars of opportunity (e.g. airport avian radars) can interface to the radar network by connecting (in parallel) to an *adjunct signal processor* (described later).

Since COTS technology following industry standards is employed, cellular networks are flexible, maintainable, upgradeable and affordable. Various user subscription plans are available so that users can acquire the tools they need. This flexibility has resulted in high adoption rates which continue to drive price-performance ratios. Multiple vendor equipment sources along with established industry interfaces ensure maintainability and upgradeability. And affordability is well established, with a growing consumer base with a seemingly endless appetite for upgrades, both in the developing and developing world. By exploiting open COTS technology, and by providing open interfaces, radar networks can achieve these same benefits.

B. *Network-Centric Architecture for Target Information Acquisition, Management and Distribution*

The radar network illustrated in Figure 1 incorporates the cellular network attributes presented in the previous section, and is further described in [1,2]. Each radar node can be viewed as a high-quality surveillance engine, providing a continuous, bandwidth-efficient, data stream of target information for every tracked target. The track information includes geo-referenced location, speed, heading, radar cross section (RCS), height (with appropriate antenna), ID, date/time stamp, etc. which are updated every couple of seconds. Each radar node consists of the COTS radar sensor transceiver (RST) and antenna, a platform on which these are mounted (e.g. roof-top, water tower, mobile vehicle, aerostat, tower, etc.), a radar remote controller (RRC), and a digital radar processor (DRP). The RRC provides for control of the RST from anywhere on the network (e.g. change radar modes, power up, standby, transmit). The DRP extracts target information from the COTS RST's "raw" radar signal every couple of seconds and then sends this information over a secure COTS network (including any TCP/IP LAN, WAN, Internet) to a Radar Data Server (RDS). The RDS is usually located at a central monitoring station (CMS) or operations center. The extracted radar target information includes both detections and tracks (detections allow for reprocessing after the fact, which is very important for investigations, prosecution and auditing purposes). The target information is stored locally (for redundancy) and is sent over the network continuously as efficiently-coded information packets.

A central Radar Data Server (RDS) (affordably scalable to a centralized or distributed server farm as the number of nodes increases) collects highly processed target information from the radar nodes and distributes them to a number of remote users. These users simultaneously, and in real-time, access TrackViewer Workstations (TVWs), GoogleEarth™ Integrated Radar Displays, other display applications, post-processors (such as Radar Fusion Engine (RFE), Target Classifiers (TC), statistical analysis radar data (SARD) processors, etc.), or other third party systems (such as common operating picture (COP) software, Command and Control (C2), and Command, Control, Communications, Computers, Intelligence, Surveillance, and Reconnaissance (C4ISR) systems and frameworks).

The RDS provides connectivity between the radar sensors and the remote users of the target information. The RDS allows complete target information to be sent to it from any networked radar location. Target track information is immediately stored for subsequent real-time or historical access. All data are stored efficiently and indefinitely in a robust industry-standard Structured Query Language (SQL) database (the Track Database) which is at the heart of the RDS. Multiple users are allowed to access the data in parallel, according to their specific requirements, for real-time viewing and analysis. Specific portions of the integrated target information are distributed to the remote users. Different users have different needs and privileges, and thus are given appropriate portions of the data. Users connect to the RDS using client applications such as the TVWs, Google Earth™ displays, Web services, etc.

Tracks are uniquely time-stamped, ID'd and maintained in the RDS so that they can be archived indefinitely as well as distributed in real-time. Tracks are also geo-located in real-time so that target coordinates are readily available for straightforward integration into the aforementioned third party systems or for use in cueing other devices (e.g. cameras). Target locations are provided in both local radar (range, azimuth) and geo-earth (latitude, longitude) coordinates. Historical track data can be played back and re-processed at rates many times faster than real-time. This allows archives to be used for analysis, intelligence gathering and prosecution either directly by users, or by third-party applications. The richness of the target data stream will even support real-time re-processing of the radar data optimized for other missions.

Such a network allows information from multiple remote sensors to be centralized, integrated and fused. Unlike more dedicated (and expensive) military systems, this design uses open COTS network technology and protocols (TCP/IP, HTTPS, Web Services, etc.) to affordably configure arbitrary secure networks. Internet and wireless network links can be used wherever needed for affordability and flexibility. Radar integration risk is reduced dramatically since the divide-and-conquer distributed architecture ensures that the heavy-lifting digital radar signal processing (including clutter suppression, detection and tracking) is done at each node. Integration with third party systems and frameworks is ever so straight-forward, since the RDS has already accomplished the radar node integration. The RDS provides a single, earth-coordinates-based, open interface that can push, be pulled and throttled, even with interruptions, as desired, without impacting radar tracking capabilities.

C. Adjunct Signal Processor

The radar network shown in Figure 1 is achieved by integrating a sophisticated, high-performance a*djunct signal processor* (ASP) with standardized COTS marine radar sensors as shown in Figure 2. This distributed and scalable ASP guards against the kind of integration risk that has challenged other programs such as SBInet's Project 28. Unlike other digital radar processors, the ASP not only addresses radar target acquisition, but also radar target information storage, management, integration & fusion, distribution, post-processing and presentation for situational awareness. It takes inexpensive radar sensors and turns them into a high-performance, wide-area, software definable radar (SDR) systems, while at that same time, providing an open, one-stop source for integrated radar information to third party systems and frameworks. The ASP sits between radar sensors, users, and third party COPs, C2 and C4ISR systems and frameworks, and by virtue of its divide-and-conquer architecture, scales with any number of sensors.

The DRP, which carries out target acquisition including clutter suppression, detection and tracking, is integrated with the COTS radar sensor, as is the RRC. For *N* radar sensors, typically *N* DRPs/RRCs are connected in a 1:1 fashion. High-performance algorithms such as the military gold standard MHT/IMM (see [3]) are responsible for good small, maneuvering target performance in dense target environments.

The RDS is responsible for target information storage, management, integration and distribution. The bandwidth required between the DRP and the RDS is typically only 100-400 kbps, even under dense target environments. As each radar node in a wide-area network typically makes its own connection with the RDS, the network scales with the number of nodes. If a public network such as the Internet is used for wide-area distribution, each radar node only requires the equivalent of a good DSL (wired) or 3g (wireless) modem to connect to the RDS. Using specialized signaling, schemas, and an underlying, open, high-performance, SQL database, the RDS provides flexible access to real-time and historical target information needed by users and post-processing applications for tactical (e.g. surveillance, interdiction, automated alerting) and strategic (e.g. intelligence gathering, investigations, prosecution) purposes. The RDS effectively transforms a number of radar surveillance engines into a wide-area, target information system that any number of users and applications can simultaneously access. With the RDS between users and third party systems and frameworks, target information integrity is assured irrespective of whether or not a downstream system can keep up with the source radar's scan rate. This architecture allows each downstream user application to pull or have information pushed asynchronously at whatever data rate it chooses up to real-time. It also supports any number of dissimilar radar sensors as described next.

D. COTS Sensors

The use of COTS marine radar sensors has several important advantages including low cost, a wide range of options, standardized interfaces, multi-vendor availability, continuous improvement, good performance, spectrum compatibility, and excellent service and support.

Marine radars are inexpensive (starting around $10k) and readily available from vendors such as Furuno, JRC, Raymarine and Kelvin Hughes. Antenna array lengths can be purchased from 4' to 18' and transmitter power is selectable from 2kW to 60kW (peak) so that the sensor can be matched to its location and mission. They are easy to mount on platforms ranging from ground level to thousands of feet AGL (on mountain tops or on the belly of an Aerostat). An industry standard interface means that an ASP can connect to any of them. Even a number of military radars use the same compatible signal interface consisting of a trigger signal, an azimuth reset (north) pulse, and azimuth change pulse, and the pulse echo return signal. Marine radars are widely deployed on recreational and commercial vessels, on shorelines for VTS systems, and at other facilities such as airports; and commercial service and support providers are available almost everywhere they are found. Using these sensors provides a sense of covertness (they don't stand out from the thousands of them found in the marine environment), as well as offering the opportunity to tap into existing radars. They are also designed for co-channel interference; and licensing to operate one is either not required (on the water) or easy to get (on shore or in-land). Good sensitivity against watercraft, aircraft and vehicles has been demonstrated [3], with full automation with an attached ASP. When fixed radars are used, they operate 24/7/365 with very little maintenance under all weather conditions, providing persistent surveillance.

In the same way that users have continually benefited from advances in computer technology, the same holds true for marine radars. Due to the size of these markets (over 1 million units sold), improvements are introduced by manufacturers on a regular basis, and as their signal interface doesn't change, they are plug-and-play to existing auxiliary systems. An important example is the recent introduction by Kelvin Hughes of solid state marine radar transceivers with Doppler processing capabilities. These transceivers offer performance enhancements in clutter-dominated situations on land or during strong precipitation.

When needed, custom antennas have been integrated with these same marine radar transceivers as illustrated in Figure 3, where 2D scanning is required from these 1D scanning radars for air search and low-flying aircraft applications.

Figure 3: Dish antenna with electro-mechanical vertical scan control, integrated with COTS marine radar. Provides 360 deg azimuth scanning with elevation angle set under software control.

E. Proven and Commercially Available

The radar surveillance framework described above is proven, with hundreds of thousands of operating hours. The Accipiter components are not a research project, but commercially available, certified products sold to law enforcement organizations, defense departments, and airports. The U.S. Department of Defense, the Federal Aviation Administration, and the Department of Homeland Security have successfully carried out multi-year independent testing of radar networks incorporating these components and architecture. These systems are in use by law enforcement on both sides of the Canada/U.S. Border including the GLSLSS.

III. EXAMPLES ILLUSTRATING BENEFITS

A. Multi-Mission Suitable

The unique access that the proposed radar surveillance framework affords users to real-time and historical target information means that both tactical and strategic needs can be satisfied through any number of situational awareness tools. These tools provide target analytics in support of surveillance, interdiction, intelligence gathering, investigations and prosecution.

Remote, real-time displays as well as automated real-time alerting and text messaging for unattended monitoring of border zones or perimeters around critical infrastructure are easily supported as illustrated in [1]. A variety of historical tools are readily available and supportable such as web access to: (1) automatically computed traffic patterns versus time (i.e. by year, month, day, hour); (2) automatically computed traffic counts in areas of interest (e.g. a border region) versus time; (3) rapid playback of tracks beginning at user-specified date/time; (4) analytics applied to stored tracks where user-specified business rules rapidly search and log behaviors such as rendezvous, border crossings, loitering around designated areas, departures from or arrivals to locations of interest, and (5) extraction of target information (complete trajectory), including RCS profiling for use in target identification (see Figure 4).

High-performance, software-definable radar processing algorithms [3] support the tracking of vessels, aircraft, and vehicles (including snowmobiles). Furthermore, RCS profiles can be extracted for targets of interest as illustrated in Figure 4 which can greatly assist in target identification and in filtering applied to automated alerts and target analytics. A large tanker, a helicopter, and 7m Zodiac, a jet-ski, and some birds are shown, with significantly different and separable RCS profiles. RCS varies from +40 dBm^2 for the tanker, down to -20 dBm^2 or less for a bird. This capability provides the means for stopping birds from triggering alerts, while still providing excellent small target (e.g. jet ski) capability. The RCS profile for a target of interest can assist in identification, especially to associate to the same vessel, suspicious movements on different days. Formal tests on Lake Ontario in May 2010 using an inexpensive X-band, 25 kW radar with a 6' array tracked the jet-ski to 15.5 km and the Zodiac to 29 km under good conditions.

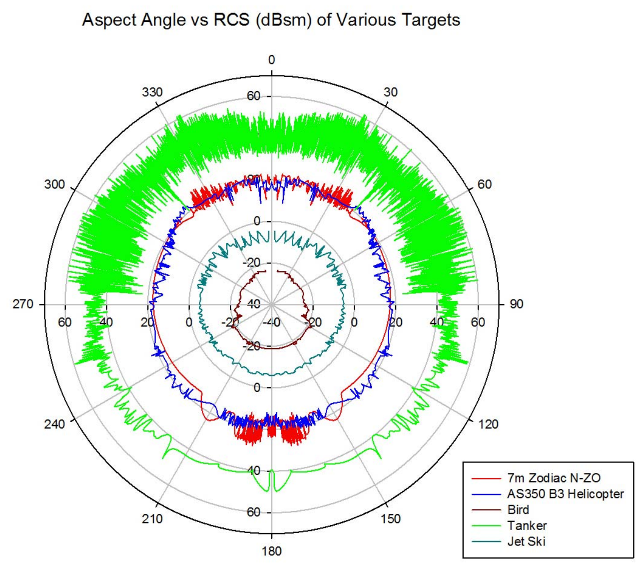

Figure 4: RCS profiles for a tanker, Zodiac, helicopter, jet ski, and bird. Units are in dBm^2 as a function of aspect angle with 0 degrees head-on.

B. Scalable

The proposed radar surveillance framework and the ASP upon which it is based are completely scalable as the number of radar nodes and users grows. With a DRP associated with each radar node, the heavy lifting is done locally and bandwidth reduction is maximized at each node. A single RDS can support many DRPs and users/user applications, and its web-server can support hundreds of users, making scalability straight forward and very affordable. Each remote user only requires a data link sufficient to support his/her own bandwidth requirements.

The radar network illustrated in Figure 5 has a single RDS that integrates six radars and supports a dozen users across two countries spanning three lakes and a harbor in the GLSLSS.

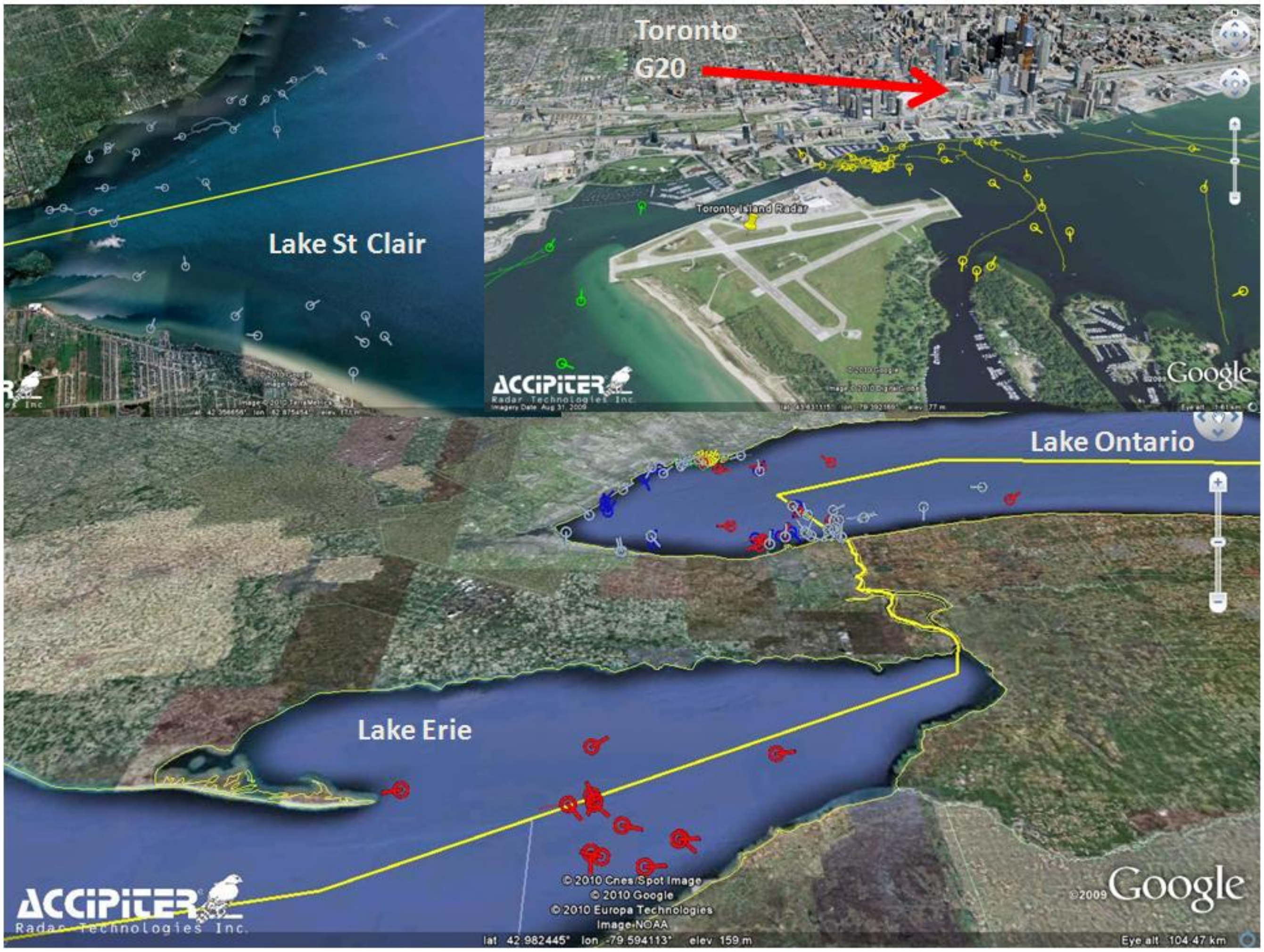

Figure 5: Six radars integrated into GoogleEarth™ COP during G20 meeting in Toronto June 25-26, 2010. Blow-ups shown for Lake St. Clair and Toronto.

The Internet sits between the DRPs, the RDS and users, with low-bandwidth, commercial, wireless (3g cellular) and wired (DSL & cable) Internet connections.

Mobile platforms are particularly beneficial for filling gaps in coverage when needed, especially for covert operations, or for special, VIP events such as G8/G20 meetings and Olympic games. In Figure 5, the two mobile platforms, one in the U.S. and the other in Canada, were deployed and seamlessly integrated into the wide-area network, for short periods on the order of months. The other four radars are fixed and hence provide persistent surveillance all year long.

C. *Flexible*

Sensor platforms can be selected as needed to keep costs down, based on the geography and line-of-sight requirements for any given node. In Figure 5, two of the radars are mobile, two sit on 80’ towers, one sits on the roof of an air traffic control tower, and the sixth is mounted on a 13’ pole at the water’s edge at the end of a runway. Radar sensors can also be selected as needed. In Figure 5, one radar is an old-style 25 kW Furuno 7252 radar, three are modern 25 kW Furuno 8252 radars, one is a more expensive Furuno 2127 radar, and the sixth is an older style JRC radar (all X-band).

Marine radar transceivers typically come with short-pulse, medium-pulse and long-pulse waveforms, which, when coupled with the software definable ASP, provide waveform selectivity to meet mission requirements. The Lake St Clair radar, and the two Toronto Island radars are both interested in fine target movements over a relatively confined (< 20 km) waterway. Hence, the short-pulse waveform provides good small target fidelity (10 m resolution). On the other-hand, the mid-Niagara-Peninsula radar (red tracks covering large vessels on both Lake Erie and Lake Ontario over 100 km away), and the two radars (blue and white) on the southern shore of Lake Ontario use long-pulse (approximately 100 m resolution). See Figure 5.

Additional flexibility is afforded by the modular nature of the ASP, allowing each radar node to only require the components it uses. This flexibility allows system owners to grow their systems as they see fit, recognizing that one shoe does not fit all.

D. Maintainable and Upgradeable

Using COTS components with standardized interfaces where multiple vendors can supply equivalent products ensures maintainability. As a component product such as a radar transceiver or computer platform reaches end of life, it can be replaced with an equivalent compatible component very easily. Commercial products ensure long system life-times and availability. In addition, the constant available of backwards compatible components means that requirements on spares can be greatly reduced resulting in cost savings.

COTS marine radar transceivers and the ASP's computing platforms are built to reliable commercial standards. Manufacturers upgrade these regularly with new features and greater performance while maintaining backwards compatibility. Hence upgrading hardware is straight forward. Upgrading the ASP software with new capability enhancements is fully supported, with upgrades implementable remotely over the built-in networks. Spiral improvements can be made to features and algorithms, and a virtually endless number of situational awareness applications that exploit target information can be developed and added by the customer directly (taking advantage of the open interfaces) or by a contractor.

E. Interoperable and Sharable

The network-centric architecture means that a system of systems is easily created through simple IP routing, and the open interfaces to the target information contained in the RDS provide the means to share specific target data with other systems or users. These technological features allow different radar system owners the flexibility to decide what information they share with whom. Filtered, non-post-processed, track information would typically be shared if there are concerns with information sensitivity. Secure users, on the other hand, could receive unfiltered (no data removed) and post-processed (e.g. fused with other information) target information.

The mobile radars (white tracks) used in Figure 5 do not have an RDS – rather, those radars talk to a central RDS located in the operations center in Niagara. On the other hand, the Toronto Island radars have their own RDS, but filter their feed to remove sensitive information before sharing their target information with the central RDS.

A feed from U.S. law enforcement radar on Lake St Clair (shown in blow-up on top left of Figure 5) is interoperable with the other five radars located in Canada. A filtered feed from Toronto Island Airport radars (green and yellow) is also shared and integrated (see blow-up on top right of Figure 5). A private radar located on the high-point of the Niagara Peninsula (red tracks) covers large traffic on Lake Ontario and Lake Erie. A shared feed from an unattended radar system (blue tracks) that monitors an area above sunken war ships in the middle of Lake Ontario [3] and issues alerts to authorities of suspicious behavior is also integrated in Figure 5.

Sharing target information will improve performance associated with mission requirements. Consider the red tracks on Lake Erie in Figure 5 that are north of the border. Those targets are further away from the U.S. yet of greater interest to Americans should they cross the border. A radar on the Canadian side will provide better target information as radar performance degrades with distance. The same holds true for targets south of the border which are of greater interest to Canada for border enforcement. Hence, with a border than runs through the middle of the GLSLSS, sharing target information from radars installed on both sides of the border is the obvious approach for improved performance.

F. Affordable

Deploying a radar network, regardless of the radar sensor and the make-up of the adjunct signal processor, will require infrastructure (tower, enclosures, power, networking) and services (installation costs). These costs are not considered below. Furthermore, life cycle costs, including technical support costs, upgrades, maintenance and replacement costs are not considered due to their wide variability, depending on requirements. Industry metrics can be applied with the understanding that the service life of the marine radar front-end can be considered about 10 years and the service life of the computer electronic devices that make up the rest of the system exceed five years.

Let's assume that radars are shore-mounted to provide persistent coverage on (and over) the water, and on adjacent road ways, and take into account empirical, small-target performance data associated with radar nodes in accordance with the wide-area surveillance framework presented herein. Then, the associated radar equipment cost (in volumes) should be as little as a few hundred dollars per square-km for unobstructed view of the larger lakes, increasing to a few tens of thousands of dollars per square-km (i.e. up to 100-fold increase) for smaller rivers (such as the St. Lawrence) and smaller bodies of water. As a whole, persistent surveillance of the entire GLSLSS is quite affordable in comparison to any other approach.

IV. DISCUSSION

A mature, and commercially available, radar surveillance framework has been presented for affordable persistent surveillance of the northern border and the GLSLSS. It's multi-mission, interoperable and shareable attributes can deliver web-based applications to everyday citizens, resulting in a *peace dividend* to society from government investment in security. For example, safety on the waterways can be improved greatly by providing target information to search and rescue personnel. Shipping, marine services companies, tourist operators, private security companies and researchers could also benefit from the information.

REFERENCES

[1] T.J. Nohara, *Affordable, multi-mission, radar surveillance networks for marine and port security*. Journal of Ocean Technology, Vol.4, No. 2, 2009 pp.29-38.

[2] T.J. Nohara, P. Weber, G. Jones, A. Ukrainec, A. Premji., Affordable high-performance radar networks for homeland security applications, IEEE 2008 Radar Conference, Rome, Italy, May 2008

[3] P. Weber, A. Premji, T. Nohara and C. Krasnor, "Low-cost radar surveillance of inland waterways for homeland security applications", in *Proc. IEEE Radar Conf*., Philadelphia, Pa., USA, Apr. 26-29, 2004.