Coalition Interoperability at the Tactical Edge: U.S. Lessons Learned From Enterprise Challenge 2016

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ABSTRACT

U.S. and coalition forces currently do not take full advantage of available mobile and fixed partner Intelligence, Surveillance and Reconnaissance (ISR) assets during coalition operations. Each coalition partner typically provides all of the ISR assets they require which creates significantly increased costs in logistics, sustainment and required personnel. As a result, the U.S. Army Research Laboratory (ARL) partnered with Defence Research Development Canada (DRDC) on a bi-lateral research and development project titled Coalition ISR Assets Interoperability (CIAI) sponsored by the Office of the Secretary of Defense (OSD) Coalition Warfare Program (CWP) Office.

The objective of this CWP project is to optimize the utility of coalition ISR assets. As part of this effort, ARL and DRDC developed a coalition plug-and-play architecture to enable autonomous cross-cueing of disparate assets with no hardware or software modifications required to the assets themselves. This was accomplished using U.S.-developed Open Standards for Unattended Sensors (OSUS) architecture to allow capability for autonomous cross-cueing, shared control and policy implementation for use of mobile and fixed ISR assets at the tactical edge. Through this effort, we hope to develop an initial baseline for a NATO Standard Agreement (STANAG) for unmanned ISR asset plug and play interoperability at the Unattended Ground Sensor (UGS) component level.

ARL participated with DRDC in Enterprise Challenge 2016 (EC-16) to conduct experimentation and demonstrations. Leveraging an Expeditionary Processing, Exploitation and Dissemination (Ex-PED) model and OSUS, the team fully integrated the Canadian assets into the event. The Canadian data was discoverable at the enterprise level, its detections noted on the 3-D Sensor Common Operating Picture (3-D Sensor COP), and was made available to the broader exercise network through data normalization which allowed the information to pass through a cross-domain security guard to the operational network.

EC-16 was conducted in July and August 2016. This paper highlights the successes and U.S. lessons learned from our collaboration with DRDC. Specifically, this paper discusses the software integration process, fielding, control and dissemination of Canadian data on a U.S. system. The EC-16 model for sensor integration, display and dissemination could have a direct impact on Theme 8, "Sensing for Decision Making".

1. INTRODUCTION

In 2011, the United States Army Research Laboratory (ARL) developed an initial operating concept to dynamically display a Sensor Common Operating Picture (COP). In the intervening years ARL refined this operational concept by asking hard questions about interoperability. If an intelligence analyst could view all available assets and see information as it is generated, could dynamic cross cuing between disparate sensors be accomplished at the tactical edge? In theory the answer was yes, at the tactical edge, where the warfighter has a greater control over its organic sources of information.[1]

Subsequently, ARL became involved in unattended ground sensor interoperability, at both the component and data level. This led to ARL's work with the Open Standard for Unattended Sensors (OSUS) architecture. OSUS provides a means for interoperability within Unattended Ground Sensors (UGS) systems through use of common software plug-in interfaces for sensors/algorithms/radios and a common lexicon/data model. OSUS allows multiple vendors to independently develop standards-compliant UGS components and systems that can subsequently be integrated together by any systems integrator (or even a knowledgeable end user) familiar with the standards.

This method greatly reduces integration time and costs compared with integration of equipment using proprietary interfaces. It promotes modularity by allowing individual system components (sensors, controllers, algorithms, and radios) to be used as commodity products so that systems can be quickly adapted to changing technology or mission requirements. For example, a radio intended for desert operations can be quickly replaced with another that is better suited to jungle operations.

The OSUS standards ensure that all UGS reports and commands are normalized. Further, the OSUS lexicon ensures a shared semantic interpretation of all data. For example, the term time can be interpreted many ways by many systems even if using the same data format. OSUS ensures that, for example, all time reports have a shared interpretation. The common data model is a powerful feature that allows third parties to develop algorithms (facial recognition, target tracking, target classification, etc.) that can be hosted in the remote system or at the enterprise level. Development of these algorithms only requires knowledge of the data model and not the sensor. In addition, these algorithms can operate on data produced by any vendor's sensor while hosted on any other vendor's controller.

The OSUS data model also supports Processing Exploitation and Dissemination (PED) operations on the enterprise by providing a unified sensor feed to the 'back end'. This greatly simplifies configuration control of software operating on enterprise systems because all sensors use the same interface (i.e., OSUS) as compared with a separate interface for each sensor. Future standards-compliant sensors can subsequently be added to the network without need to modify software on the enterprise. This greatly minimizes changes to enterprise software and the associated issues of regression testing and information assurance accreditation.[2]

[1] S. Toth, W. Hughes, A. Ladas, "Wide-area Littoral Discreet Observation: Success at the Tactical Edge," *Proc. SPIE 8389, Ground/Air Multisensor Interoperability, Integration, and Networking for Persistent ISR III*, 838916 (May 1, 2012)
[2] G. Stolovy, J. Houser, "Sensor Interoperability Using Open Standards for Unattended Sensors (OSUS)," *IST-SET 126 RSM Symposium on Information Fusion (Hard and Soft) for ISR*, Norfolk, VA, (May 2015).

Finally, in 2016, ARL partnered with the Defence Research Development Canada (DRDC) on a bi-lateral Research and Development project on Coalition Intelligence Surveillance and Reconnaissance (ISR) Assets Interoperability (CIAI) sponsored by the Coalition Warfare Program (CWP) Office.[3]

The objective of CIAI is to optimize the utility of coalition ISR assets and is planned to be accomplished with two major thrusts. The first thrust developed a coalition plug and play architecture to enable autonomous cross-cueing of disparate assets with no hardware or software modifications to the asset. Through this effort, we hope to develop an initial baseline for a NATO STANAG for unmanned ISR asset plug and play interoperability at the UGS component level.

In the second thrust of this project, the U.S. and Canada will develop novel ISR interoperability concepts, agile algorithms and tools to implement a Missions to Means Framework (MMF) to enable the discovery of available ISR information sources (assets) and best match these available ISR assets (means) to the mission-informed information needs required for situational understanding in the dynamic and often ad-hoc nature of coalition operations. [4]

With this as background, ARL and DRDC participated in Enterprise Challenge 2016 (EC-16), an experimentation event directed by the Under Secretary of Defense for Intelligence (USD (I)) and executed through the National Geospatial-Intelligence Agency (NGA). This paper will address ARL's lessons learned on enabling interoperability at the tactical edge.

2. ARL EC-16 Technologies

ARL brought a suite of tools and a self-contained local area network enterprise to EC-16 as shown in Figure 1. The data technologies include: 1) Infrared Motion Detection (IrMD) wide area motion detection, 2) U.S./Canadian UGS and 3) RF links. The US/Canadian sensor assets were interoperable within a ground sensor network via ARL's Open Standards OSUS. The PED technologies included: 1) Roll-on Roll-off PED System (RoRo), 2) 3-D terrain viewer (Fusion3D), 3) OSUS, 4) Sensor Assignment to Mission (SAM) tools 5) data repository, 6) Visualization tools, and 7) Distributed Common Ground System – Army (DCGS-A) Emulator.[5]

[3] Coalition Warfare Program (CWP): http://www.acq.osd.mil/ic/cwp.html

[4] T. Pham, G. de Mel, J. Schoening, R. Gagner, "Sensor and Information Fusion for Actionable Intelligence at the Tactical Edge," *NATO IST-SET-126 RSM Symposium on Information Fusion (Hard and Soft) for ISR*, Norfolk, VA, (May 2015).

[5] For complete details on the technologies deployed to EC-16 see S. Toth; W. Hughes; T. Pham; J. Houser "ARL PED Efforts at Enterprise Challenge 2016" *Proc. SPIE 9831, Ground/Air Multisensor Interoperability, Integration, and Networking for Persistent ISR VII*, 983107 (12 May 2016)

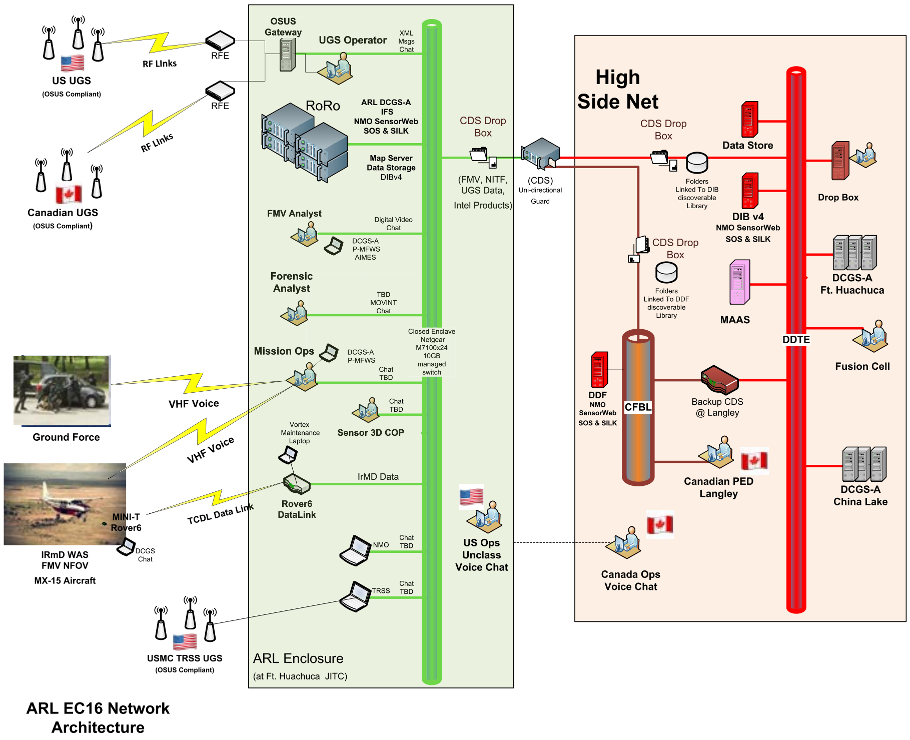

Figure 1- ARL EC16 Network Enterprise Diagram

3. INTEGRATING CANADIAN SASNET WITH OSUS

One of the major goals at EC-16 was to integrate the DRDC-developed Self-healing Autonomous Sensor Network (SASNet)[6] sensor system with the OSUS interoperability architecture, demonstrating interoperability between Canadian assets and US assets.

Many interoperability architectures focus on system-level interoperability at the message level, defining standardized message sets and protocols that systems will use to exchange data over a network. In contrast, OSUS focuses on component-level interoperability within a system at the Application Interface (API) level, while (out of necessity) also defining standardized representations for sensor observations and commands. The OSUS specification defines a standard set of APIs that software components, called plugins, use to interact with each other. There are multiple classes of plugin: asset plugins, essentially device drivers that convert between a sensor's native protocols and formats and the standard OSUS APIs and formats; communication plugins, which serve the same function for (non-IP) radios; and extension plugins, which wire other components together to perform business logic and carry out other functions. OSUS is based on Java and OSGi[7] and can run on any system capable of hosting a JAVA Virtual Machine from low power embedded controllers to desktops, laptops, and enterprise servers. The OSUS reference implementation (OSUS-R) provides a controller software framework along with a Graphical User Interface (GUI) (OSUS-SG) that can be used to configure and program controllers.

[6] DRDC Information Sheet SASNet – Military UGS Development in Canada
[7] OSGI Core Release 5; The OSGI Alliance: San Ramon, CA, March 2012.

There were several subtasks involved with the EC-16 OSUS interoperability effort, all of which were successfully accomplished.

3.1 Integrate U.S. and Coalition partner sensors with OSUS controllers and control all UGS attached to the controllers

At EC-16, ARL provided the following OSUS-compatible devices:

- OSUS controllers based around an in-house hardware design (an industrial x86 system-on-module with a custom-built carrier card.)
- Sensor devices representative of currently fielded UGS systems, including Battlefield Anti-Intrusion System (BAIS) activity detection sensors, Tactical Remote Sensor System (TRSS) imagers and activity detection sensors, and Scorpion imagers.
- Experimental sensor devices, including the C429 motion detection camera built around low-cost COTS hardware.
- Communications devices, including the military-band Common Sensor Radio (CSR) along with commercial LTE cellular modems.

Many of these devices had been developed or integrated for previous projects. These existing integration plugins and components were easily reused at the EC-16 exercise.

DRDC provided the following OSUS-compatible devices:

- The SASNet seismic-acoustic sensor system, consisting of sensor nodes with integrated radios that communicate with a base station “sink node”.
- OSUS controllers based around a commercial-of-the-shelf (COTS) embedded controller (a BeagleBone Black[8]

During preparations for EC-16, DRDC integrated the OSUS controller software onto their controller hardware, and also developed OSUS asset plugins for the SASNet system.

To demonstrate coalition interoperability at EC-16, some of the (U.S.) ARL-provided sensors were successfully connected to (Canadian) DRDC-provided controllers, and the DRDC-provided SASNet sensors were successfully connected to ARL-provided controllers. Because all controllers exposed the same software APIs and hardware interfaces, regardless of which country and lab provided them, the integration was seamless and was accomplished with a minimum of effort. It took four days to develop and integrate the appropriate OSUS interface in order to integrate Canadian sensors fully into the experiment, and there was no need to reconfigure any proprietary format unique to SASNet.

3.2 Transfer and execute OSUS compatible Mission Programs on the OSUS controllers to autonomously cross-cue disparate coalition ISR assets

OSUS provides mechanisms for mission programs (the business rules that specify which actions should be taken when particular events occur) to be implemented in a device-independent manner. ARL provided a set of extension plugins that implemented the mission program for EC-16, cross-cuing assets within and across controllers based on a distributed set of rules that could be changed on the fly. Other extension plugins provided by ARL handled data distribution between controllers and the gateway. These plugins can operate

[8] For technical details see https://beagleboard.org/black

in both real-time and store-and-forward modes and can use either IP radios (such as LTE modems) or non-IP OSUS compatible radios (such as the Common Sensor Radio). These plugins relayed sensor observations to the gateway and were also used by the cross-cuing mission program to relay trigger messages between controllers.

At EC-16, these mission programs autonomously cross-cued both US and Canadian assets, using events produced by a US asset to cue a Canadian asset and vice versa. Additionally, system operators were able to update the cross-cuing rules remotely as the exercise scenario evolved.

3.3 UGS data conversion to common standard format and transmission of standardized observations via the ARL private LAN

Data was successfully converted to a standard format in two stages. On the downrange controllers, plugins for each connected asset converted between asset native protocols and standardized OSUS lexicon observations and commands. These standardized observations were then relayed to the OSUS gateway. At the gateway, observations were converted to Open Geospatial Consortium (OGC) SensorML reports and sent to the Measures and Signatures Intelligence Enterprise Service Bus (MASBUS) enterprise sensor management system provided by the National MASINT Office (NMO)[9]. MASBUS was connected to a cross domain guard that sent data to the exercise enterprise network. Because the downrange controllers produced observations in a standard format, the OSUS-to-MASBUS converter plugin could handle all observations in a generic manner, with no system or device specific code or knowledge required.

UGS data from the gateway successfully passed through the guard to the enterprise. There were issues passing JPEG2000 images, but that was a guard issue and not a data standards issue. Of importance, the Canadian UGS data, using the SensorML/MASBUS schemas, was available to the broader exercise enterprise.

Working with ARL's OSUS gateway and the MASBUS XML message formats allowed the RoRo to ingest, store and federate sensor data from a wide variety of US and coalition unmanned ground sensors. This provides us a good working baseline as we move toward standardization of sensor discoverability and normalization of data formats. Achieving these goals will enable smart platform level collection management and control of sensors and data sharing with our coalition partners. Furthermore, the MASBUS schema is the foundation for the proposed NATO STANAG 4789 Sensor Integration Standard for NATO ISR Operations[10]. Our collaborative efforts with NMO proved the MASBUS standards can work in a coalition environment.

4. SENSOR DATA IN THE 3-D TERRAIN VIEWER

Visualizing sensor positions and data on a terrain map makes it easier for an analyst to monitor multiple sensors that have been distributed over an area and make sense of the information that they provide. For example, proximity sensors positioned along a road can indicate the trajectory of a moving object along that road by showing, in real-time, the sensors being triggered. The trajectory of the object can be inferred from the order in which the sensors are triggered. The analyst may then observe that a camera sensor has been placed along

[9] MASINT Enterprise Service Bus Overview provided by Riverside Research, www.riversideresearch.org

[10] Draft NATO STANAG 4789 uses current and emerging Open Geospatial Consortium Standards (http://www.opengeospatial.org/) to define a data schema to allow for sensor interoperability with respect to integration of sensors into a common NATO intelligence picture and sensor planning services.

that trajectory. By viewing the image captured when that sensor is triggered, the analyst may be able to identify the moving object.

For the EC-16 exercise, we leveraged an existing 3-D terrain visualization tool that was developed at ARL, called Fusion3D[11], to provide an interactive interface to allow an operator to simultaneously visualize multiple sensors. Fusion3D uses a 3-D display (or projector), 3-D glasses, and a 3-D mouse to quickly view province-sized 3-D maps in stereo. It includes many useful features to aid a user in the exploitation of 3-D terrain data, such as tools for route planning, line-of-sight visualization, and distance/elevation measurement. Additionally, Fusion3D is capable of visualizing data from a variety of sensors and 3-D reconstruction approaches, including LIDAR and photogrammetry-derived point clouds. For EC-16, the 3-D map was generated from a BuckEye[12] UNCLASSIFIED color imagery and LIDAR elevation dataset that was collected in September 2015.

To meet the requirements of the exercise, Fusion3D was modified to support overlaid real-time data onto the 3-D terrain data. The modifications consisted of monitoring a network of sensors; retrieving the positions, status, and data associated with each sensor; and then displaying that information in real-time on a 3-D map. To do this, Fusion3D reads XML files that have been written to a shared folder on a private network. It then parses the files and reads the relevant data for placing the sensor in the correct location and for displaying sensor observations and observation data. The modified version of Fusion3D was demonstrated on a network of approximately 30 US and Canadian sensors of various types (proximity, acoustic, visible/IR cameras), distributed on the ground across a test range, as shown in Figure 2.

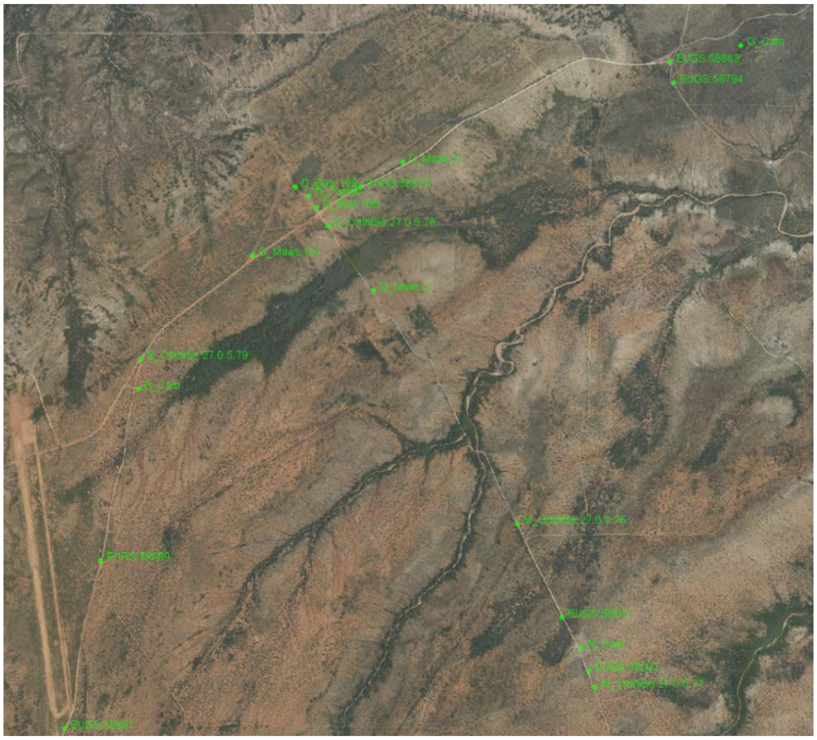

Figure 2: Overhead view from the 3-D Sensor COP showing sensor locations[11]

[11] D. Conover; J. Dammann, Jr. “Three-Dimensional Sensor Common Operating Picture (3-D Sensor COP)” *ARL-TR-7922* (January 2017)
[12] cac.agc.army.mil/Products/BuckEye/AboutBuckEye.cfm

An analyst could then interact with the data by clicking on a sensor icon, and information about that sensor was displayed. When a sensor is triggered, the corresponding icon changes from a small green circle to a large red circle, and the sensor data are displayed on the 3-D map, as shown in Figure 3. As time passes, that red circle gradually decreases in size until a time threshold is passed and the icon becomes green again. By looking at the sizes of the red circles, an analyst is able to see the sequence in which the sensors were triggered. This gives the user an idea of the direction of travel for the object being tracked.

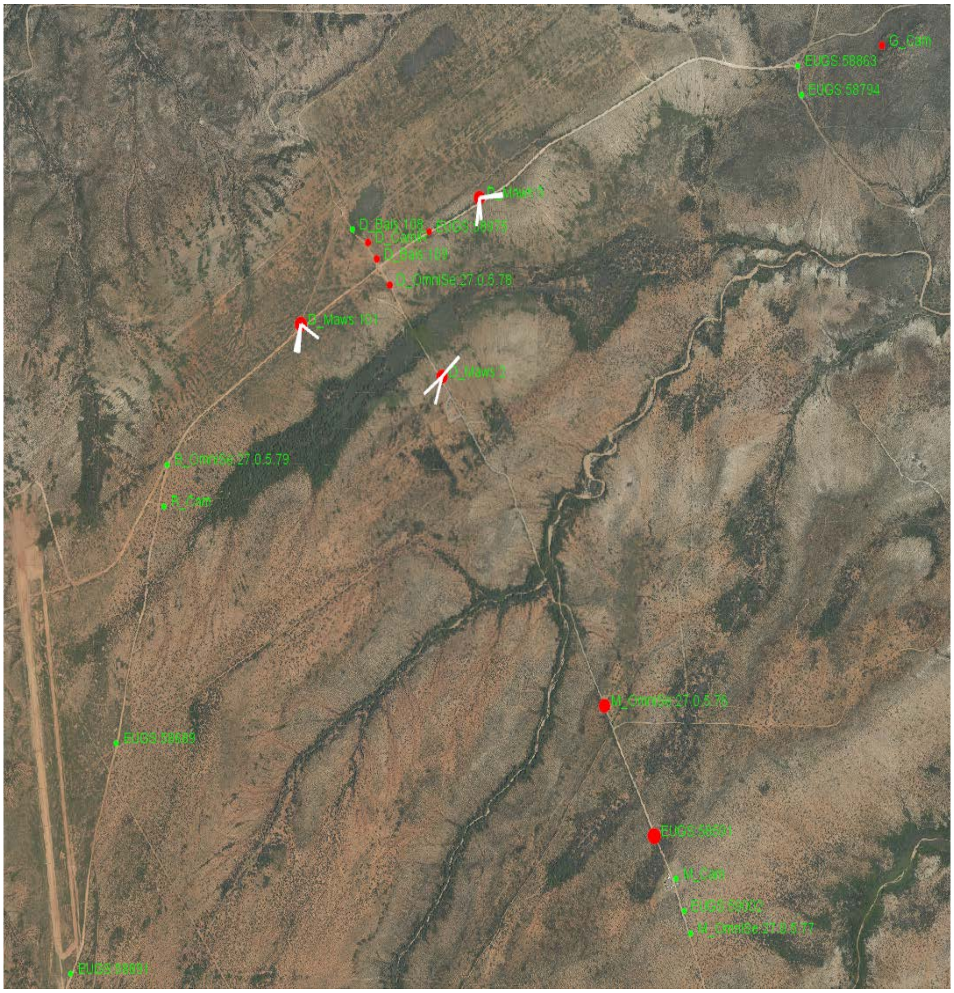

Figure 3: Overhead view from the 3-D Sensor COP showing sensor locations and observations[11]

Proximity detections are shown as solid red circles that gradually decrease in size. If a new detection does not occur, they will eventually turn green again, indicating that they have been reset back to a listening state. If the sensor data include a line of bearing, that bearing is a shown on the map as a line pointing from the sensor position toward the location of the object that caused the detection, as shown in Figure 4. These directional sensors are acoustic, so lines point in the direction of loud noises, such as passing vehicles.

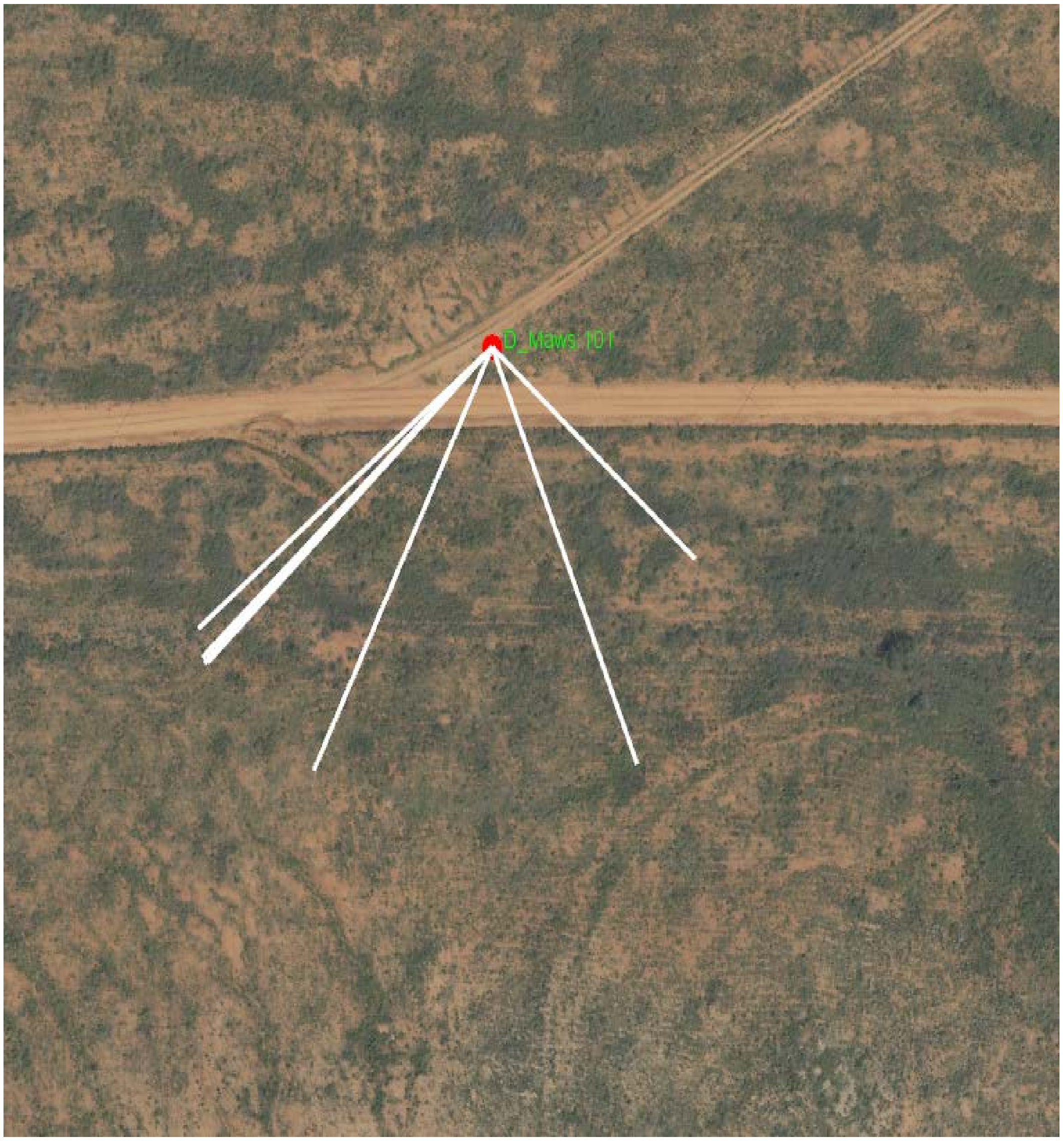

Figure 4: Observation from an acoustic sensor showing the lines of bearing of the detections[11]

For an image sensor, when a detection occurs, a user can click on the sensor icon and the image captured by that sensor is displayed on the map, as shown in Figure 5. While the other sensors provide evidence that an object is near, the imaging sensors give the analyst the opportunity to identify the object or the activity being performed.

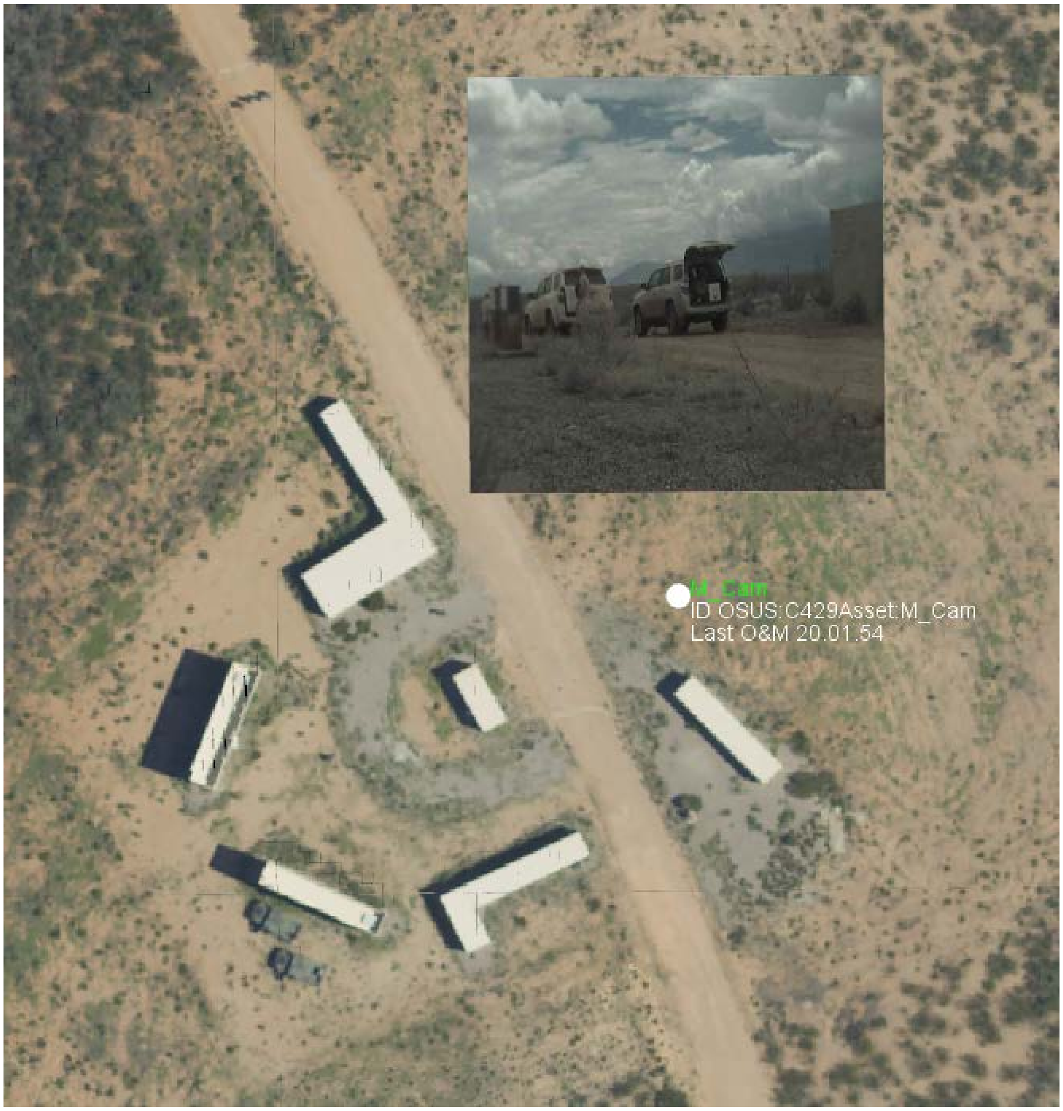

Figure 5: Observation from an imaging sensor[11]

Fusion3D was also modified to read STANAG-4607 (2010)-compliant tracks transmitted down from the IR motion detection (IRMD) aircraft and place icons indicating moving objects on the 3-D map. Figure 6 shows blue icons for detected moving objects. The moving object icons will gradually decrease in size and eventually disappear after a time threshold is exceeded. The icons along the road seem reasonable, while those off the road may be false detections. With some improvements to the IRMD moving target detection algorithm, a user would be able to see icons, indicating detected moving objects, appear in areas where ground sensors were not placed.

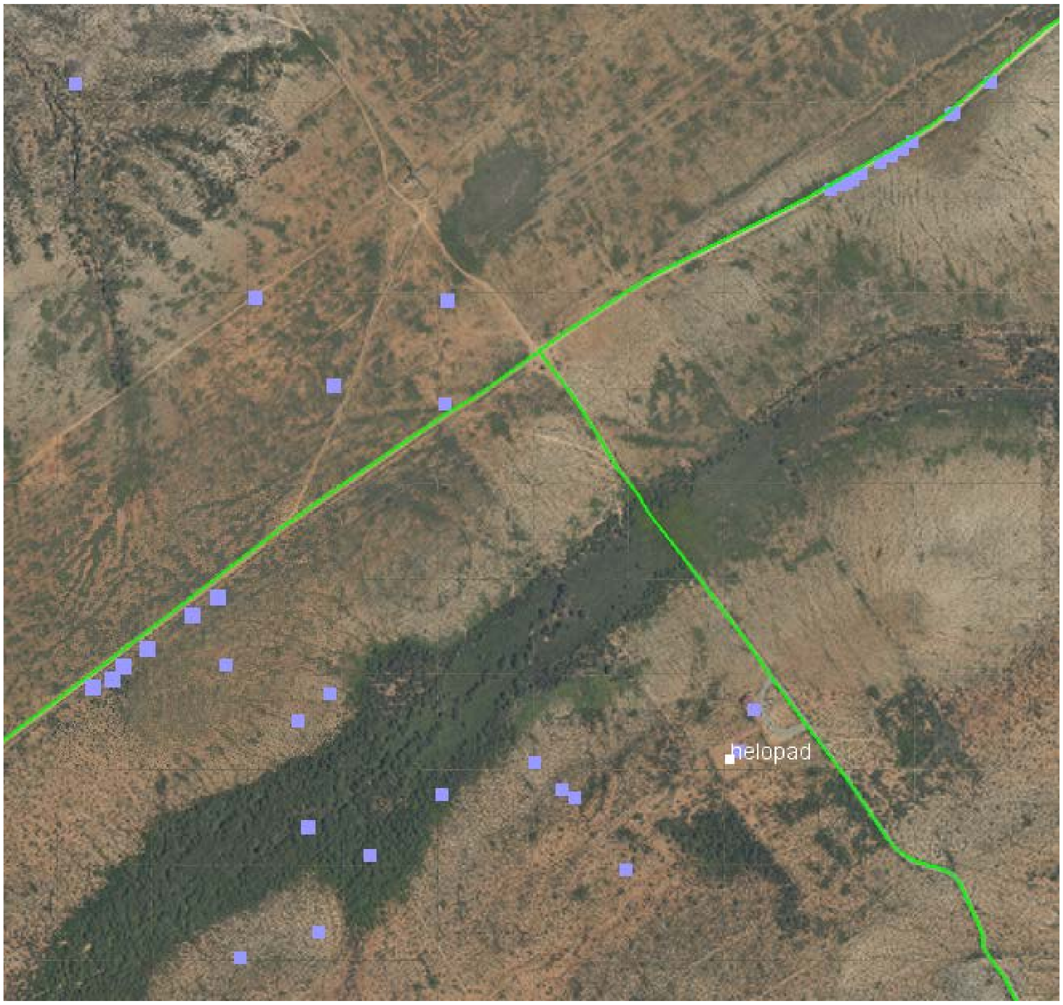

Figure 6: Moving objects identified by the IRMD aircraft[11]

Functionality that was not utilized during EC-16 is the ability to use Fusion3D to aid in sensor placement planning. Because Fusion3D is a 3-D viewer, the analyst is capable of zooming in on a potential sensor location to see the local terrain. By seeing what the sensor would "see", the analyst can determine if the sensor location meets the desired requirements prior to undertaking the mission to deploy it. For example, the field of view of an imaging sensor can be checked prior to placement to make sure that the desired area for surveillance is visible and free of obstructions. This functionality can help determine when the necessary number of sensors are deployed, as well as reduce the frequency with which sensors need to be moved after placement.

5. THE IMPORTANCE OF COALITION INTEROPERABILITY AT THE TACTICAL EDGE[13]

5.1 We Live in a Resource Constrained Environment

It is no longer sufficient to address ISR needs with newer and better sensors. Funding for new sensors is simply not as available as it was. Every coalition partner faces the same question of resources. So why should we be limited to those tools found in our national tool kits when simple software interfaces can provide information across the enterprise with limited burden to the enterprise?

5.2 We Don't Fight Alone

United States' history is rich with examples of engaging in coalition operations; we simply do not fight alone. However, because of outdated regulations, policies that discourages sharing, and export regulations that limit our ability to work even with our closest partners, we are unable to truly operate seamlessly in a coalition environment. EC-16 served as a test platform to integrate U.S. and Canadian sensors together on a single network. OSUS allowed us to tip and cue between US and Canadian sensors and provided the flexibility to control each other's assets as appropriate. As a result of our experiences at EC-16 we believe impediments to coalition-level information sharing are the result of shortcomings in policy, rather than in technology.

5.3 Data to the Tactical Edge

The tactical edge is both bandwidth and personnel constrained, but that doesn't mean it needs to be information poor. At EC-16 we deployed a PED system that contained virtualized DCGS-A functionality, supported multiple DIB/ DDF instances as well as coalition federation, and could support airborne operations – all within the confines of four transit cases. This small footprint, with its low size, weight and power requirements brought the power of big data to the most resource constrained customer. The paradigm shift we are talking about in terms of integrating coalition sensors, could provide a modular approach to deployment of intelligence and operational resources.

5.4 Break the Ops/Intel Data Paradigm by Making All Information Discoverable

Even given an open sharing environment, truly sharing information across the operational and intelligence domains remains elusive. Often data is binned as either intelligence data or operational data. It exists on different platforms and is not easily shared across the enterprise by these distinct communities. But if we can make all data discoverable, regardless of who the data owner is, each side of the Ops/Intel worlds will have access to more data. More importantly, each side will have access to more relevant data. Intelligence may own ISR, and Operations may own Force Protection, but surely the information derived from each of those efforts is beneficial to the whole. If we are able to then consolidate coalition data into a single enterprise we can move towards true interoperability.

[13] S. Toth; W. Hughes; T. Pham; J. Houser "ARL PED Efforts at Enterprise Challenge 2016" *Proc. SPIE 9831, Ground/Air Multisensor Interoperability, Integration, and Networking for Persistent ISR VII*, 983107 (12 May 2016)