Communications and Sensor Management A Net-Centric Semantic Web Approach

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Abstract

The US military requires intelligence, surveillance, and reconnaissance (ISR) information in near real time. Today's capability normally requires one or more days. Multiple key efforts related to Semantic Web technologies are presented and how they can be extended in order to manage an ISR platform's communication and sensor systems to reduce the time required in providing ISR requests to combat personnel.

1.0 Introduction

Sensors on board US Air Force (USAF) aircraft, unmanned air vehicles (UAV) and satellites are tasked to provide intelligence, surveillance and reconnaissance (ISR) information. If a US warfighter desires to know what exists beyond a mountain for instance he/she may request the latest intelligence and sensor data concerning that area. The request is radioed into a command center where analysts search databases to determine if the information is available, whether it is current and whether it suffices the need of the requestor. If the information does not exist, then an analyst will create a plan for a sensor platform to gather the information during its next flight (or when a satellite passes over the region of interest). Once an airborne sensor flight occurs and the aircraft has landed the information is processed, exploited and then forwarded on to the command center and then onto the requesting Army commander. This process can take one or more days.

There are numerous on going efforts within the military to shorten the time between an ISR request and its delivery. At the heart of this motivation is a Department of Defense (DOD) directive for a Net-Centric data strategy [1]. One of the thrusts of this directive is to post information before processing and to stop processing, exploiting and then disseminating the information. This approach will shorten the time in the above example once the plane has landed. It would shorten the time even more if the aircraft would use its communications equipment on the aircraft and send the sensor data to the ground before landing.

This paper will review some of the more important efforts that are addressing the above issues dealing with managing the communications and sensors onboard an a mobile platform. Many of the efforts are leveraging technologies developed by the World Wide Web Consortium (W3C) and the Defense Advanced Research Project Agency's (DARPA) DAML program to define the next generation Internet, also called the Semantic Web. In the near future, advanced intelligent sensor systems will perform signal and data processing cooperatively within and between platforms of sensors and communication systems while exercising waveform diversity, perform multistatic processing, as well as reconnaissance, surveillance, imaging and communications within the same sensor system. In addition, these sensor platforms will cooperate with other users and sensors sharing information and data as defined by Communities of Interest (COI). A COI is "A collaborative group of users that must exchange information in pursuit of its shared goals, interests, missions, or business processes and therefore must have shared vocabulary for the information it exchanges" [2]. The DOD Net-Centric Data Strategy is a vision for managing data within the Global Information Grid (GIG) in a way that is visible, accessible and understandable [1]. In the near future a radar sensor will participate in multiple COIs simultaneously, in areas such as wide area surveillance, battle damage assessment, and target detection under trees, producing and consuming Net-Centric data and information in real-time via the GIG.

Section 2 briefly describes the Semantic Web and its technologies. Section 3 presents select areas of research that is leveraging these technologies for sensors and communications resources. Section 4 presents system level efforts using Net Centric architectures. Section 5 discusses how to leverage these different approaches for integrating ISR and communications to provide information to military users. Section 6 presents our conclusions.

2.0 Semantic Web

The current Web allows one to obtain data and information distributed over multiple heterogeneous computers. The browser and HTML (Hypertext Markup Language) technology has brought this capability to fruition. However, a large part of the data presented is for human consumption. The next generation Internet, sometimes called the Semantic Web, has a more futuristic goal.

"The Web was designed as an information space, with the goal that it should be useful not only for human-human communication, but also that machines would be able to participate and help. One of the major obstacles to this has been the fact that most information on the Web is designed for human consumption, and even if it was derived from a database with well defined meanings (in at least some terms) for its columns, that the structure of the data is not evident to a robot browsing the web. Leaving aside the artificial intelligence problem of training machines to behave like people, the Semantic Web approach instead develops languages for expressing information in a machine processable form." [3]

The main technologies of the Semantic Web are contained within a set of layered specifications. The current components are the Resources Description Format (RDF) Core Model, the RDF Schema and OWL the Web Ontology Language. These languages are built on Uniform Resource Indicators (URI), eXtended Markup Language (XML) and XML namespaces. The W3C describes RDF as:

"The Resource Description Framework (RDF) is a language for representing information about resources in the World Wide Web. It is particularly intended for representing metadata about Web resources, such as the title, author, and modification date of a Web page, copyright and licensing information about a Web document, or the availability schedule for some shared resource. However, by generalizing the concept of a "Web resource", RDF can also be used to represent information about things that can be identified on the Web, even when they cannot be directly retrieved on the Web. … RDF is intended for situations in which this information needs to be processed by applications, rather than being only displayed to people. RDF provides a common framework for expressing this information so it can be exchanged between applications without loss of meaning." [4]

The RDF Schema is part of the RDF and it "…describes how to use RDF to describe RDF vocabularies. The specification also defines a basic vocabulary for this purpose, as well as an extensibility mechanism to anticipate future additions to RDF." [5]

Another level above RDF is OWL, the Web Ontology Language, a descendant of DARPA's DAML program's DAML+OIL (Ontology Inference Layer) ontology language.

"The OWL Web Ontology Language is designed for use by applications that need to process the content of information instead of just presenting information to humans. OWL facilitates greater machine interpretability of Web content than that supported by XML, RDF, and RDF Schema (RDF-S) by providing additional vocabulary along with a formal semantics" [6].

An RDF document is the description of the format of a resource. An OWL ontology is the description of the meaning of the content of a resource so that software can understand its contents. What exactly is an ontology? "An ontology is a specification of a conceptualization" [7]. The goal of an ontology is to define those terms within a domain and reference other ontologies necessary to complete a machine's understanding. Using this, a software agent built to understand an ontology will be able to collate and cross reference content across resources, and draw conclusions from information found in more than one source. As an example one could define an ontology for sensors where one would define the terms (classes) necessary to describe a sensor. Each sensor would then be defined in a RDF document using the terms from that ontology and other higher-level ontologies. Software would then be able to look at many sensors from many manufacturers and be able to collate the data from all the sensors and provide a coherent analysis. These higher level ontologies will come from prominent widely-accepted organizations.

Ontologies are also allowed to contain logic or rules about the domain of interest. Smart agent software that understands multiple ontologies, combined with an inference engine, will allow the building of intelligent information systems that can span multiple domains of interest. Intelligent systems across multiple domains can be integrated seamlessly, allowing these software agents to infer results that today can only be done from multiple heterogeneous data sources, software translation tools, and numerous hours to manually obtain similar results.

3.0 Semantic Web Technologies – Applications

Semantic Web technologies are not only useful in building the Semantic Web and the next generation of intelligent information systems. They are also being investigated and used for other applications. In this section a discussion of some of these approaches are presented.

Intelligent Mobile Proxy (IMP)

An US Air Force effort entitled "Providing Information Anytime, Anywhere and on Any Device" is a research and development effort to build a prototype distributed infrastructure for the derivation and dissemination of data, knowledge and information using the Joint Battlespace Infosphere (JBI) Publish and Subscribe (P/S) paradigm [8]. The prototype is a dynamic client of the JBI architecture, developed for extending a standard client to one where a user's computing device can vary substantially in hardware, software and connectivity.

Today's Internet user is able to connect with the net at any time using any of a wide variety of devices, each with different hardware and software capabilities. This effort's emphasis is to provide methods for users to interface with a JBI infrastructure that will support the efficient rapid access to distributed knowledge base repositories. The resultant knowledge will be intelligently disseminated to clients independent of computing device or connection (See figure 1.). This software functions as a proxy for the user, and is called IMP, Intelligent Mobile Proxy.

The IMP is designed to utilize the appropriate Semantic Web specifications and standards from the W3C and the DAML program. Ontologies are used so that the system can add new devices and networks on the fly by understanding the features and capabilities they have. The information forwarded to the users is adapted to reflect these features and capabilities.

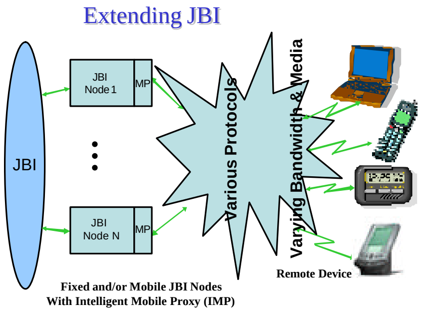

Figure 1. Intelligent Mobile Proxy (IMP)

An Intelligent Platform Network (IPN)

Another ongoing effort within the US Air Force is concerned with integrating sensors and waveform diversity. If a radar/communication sensor is going to share and receive information from multiple sources, it must be able to communicate and to understand the information. A solution for the exchange of information between heterogeneous sensors is for each sensor to publish information based upon an agreed upon and understood format (i.e. an ontology). Sharing information between sensors on the same platform and between platforms is required, especially if one or more sensors are adaptively changing waveform parameters to meet the demands of a changing environment. Figure 2 depicts a preliminary architecture design of an intelligent sensor system. Each sensor has its own signal and data processing capability. In addition to this capability, the system requires an intelligent processor to manage sensor fusion, communication and control. The goal is to build this processor with the ability to interface with any sensor and communications equipment and to communicate with the other sensors using ontology-defined data via an intelligent platform network. The intelligent network will coordinate the communications between the sensor and communication equipments onboard and off board. The network will determine if there is any electromagnetic interference (EMI) potential when a sensor varies its antenna's main beam pointing vector, or changes its pulse repetition frequency (PRF) and causes interference to a receiver. Rather than have each radio frequency (RF) equipment operate as an independent device on a platform, the IPN will function as a system of cooperating RF devices with individual and global goals.

The design presented in figure 2 has three levels of artificial intelligence (AI) algorithms to share information. The first set of algorithms is contained within the knowledge based (KB) Signal and Data Processing (KBSADP) and represents the work being performed on DARPA's KASSPER program and by the USAF Sensors Directorate [9-18]. For communications equipment, this work is being pursued under DARPA's XG program [19]. The next level of AI algorithms interfaces KBSADP with the intelligent platform network.

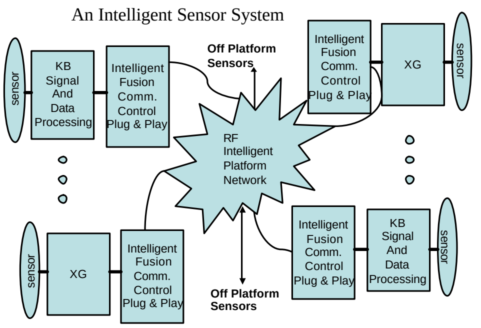

Figure 2 Preliminary Architecture Design

The Intelligent Fusion Communication Control, Plug & Play (IFC2P2) software module will share information with the KBSADP and XG modules and the IPN based on the ontologies. This sharing will allow each sensor and communication system to request/provide information from/to other sensor and communication systems for intelligent processing. For existing sensor and communication systems, software will be created to translate data to/from their own specific data formats to the formats defined by a common ontology. The IFC2P2 processor may have a graphical user front end to view information, control the KBSADP processor, and assess the results of the sensor fusion. Sharing information is valuable for new sensor systems in order to exercise waveform diversity functions, as well as for older systems lacking waveform diversity functions.

Next Generation (XG) Program

The XG (neXt Generation Communications) program is sponsored by DARPA. This program is developing an architecture that will open up the spectrum for more use by first sensing and then using unused portions of the spectrum. As stated in [19]

“The goals of the XG program are:

1. Demonstrate through technological innovation the ability to utilize available (unused, as opposed to unallocated) spectrum more efficiently.
2. Develop the underlying architecture and framework required to enable the practical application of such technological advances.”

Figure 3 is a logical functional diagram of the concept of operations of XG’s policy-agile spectrum user, which uses a computer understandable spectrum policy capability. The major components are the Sensor (which senses the environment for determining its availability), Radio (the communications device that can dynamically change its emission and reception characteristics), Policy Conformance Reasoner (manages spectrum policy information), and System Strategy Reasoner (manages the multiple radios on a platform).

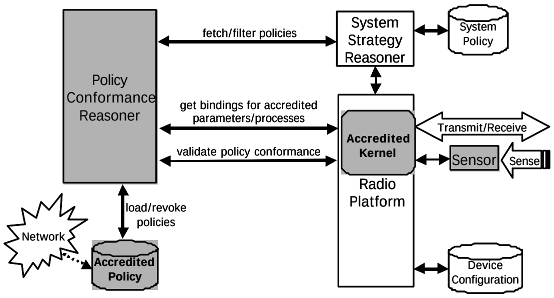

Figure 3 Policy-Agile Operation of XG Spectrum-Agile Radio

The last two components are of particular interest in that they utilize Semantic Web technologies. Operating a radio in different parts of the world requires that radios abide by the policies in the area where they are located. The XG program is developing its own XG policy language (XGPL) which uses OWL as its standard representation and will be implemented within the Policy Conformance Reasoner. The System Strategy Reasoner is consistent with the same goals as the IPN discussed above, which is also utilizing Semantic Web technologies.

4. System Level Net Centric Efforts

In concert with the above efforts there are system level efforts that are attempting to integrate numerous resources in a Net Centric manner. A key program that is developing the software architecture and processes for sharing of sensor data is the Joint Single Integrated Air Picture Systems Engineering Organization (JSSEO). They are pioneering the necessary DoD enterprise-scale engineering processes that will evolve legacy systems into collaborative command and control (C2) System-of-System (SoS) for network-centric operations in Joint and Coalition tactical aerospace battle management command and control (BM/C2). The process was applied to the Joint Requirements Oversight Council (JROC) requirements to develop a Single Integrated Air Picture (SIAP) capability for the purposes of allocating resources and ordnance to perform net-centric warfare. The goal of the JSSEO was to develop a SIAP instantiation that is a Platform Independent Model (PIM) that will be integrated within multiple, heterogeneous existing and in-development combat systems.

Specifically, the software product is an Integrated Architecture Behavior Model (IABM) that ties the DoD Architecture Framework v1.0 (DODAF) to requirements using the JSSEO's process that applies the Object Management Group Model Driven Architecture and supporting tools (i.e., Telelogic's DOORS and System Architect). The IABM is tailored and integrated into the system software components of the weapon, sensor and command and control systems i.e., global information grid (GIG) edge devices. See figure 4 for a notional view of an IABM instantiation [20].

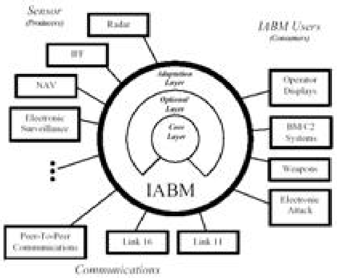

Figure 4. IABM Notional Configuration (JSSEO)

Figure 4 A Notional IABM Configuration

It can be seen that the IPN and the Intelligent Fusion Communication Control Plug and Play nodes in Figure 2 are performing some of the same functions as the IABM. The arrows going off the platform are communicating to the GIG via a publish and subscribe paradigm as illustrated in Figure 5.

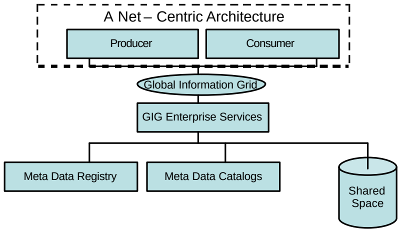

Figure 5: A Net-Centric Approach

The metadata registry contains information about the data and domains that are using the GIG. It contains such things as domain ontologies, DoD Metadata Standards (DDMS), and commonly used reference data. Its contents contain information about the format, structure, relationships between data elements, and the definitions of the data that are in the shared space. The Meta Data catalogs are instances of the metadata described in the metadata registry and allow users and applications to find data assets stored in the shared space. The metadata catalogue has at least one entry for each data asset or element contained within the shared space.

The Distributed Common ground System (DCGS) and its Integrated Backbone (DIB) is another major DoD program that will provide Net-Centric operations for all the services. Each military service has its own program and will interface their components with the USAF's DIB. Each component within the military will be able to post or publish information to a Net-Centric architecture as shown above and these data will be integrated with other information objects to create and publish additional information objects such as battle management awareness, damage assessment, target identification, etc. Raytheon [21] states that "DCGS will provide continuous on-demand intelligence brokering to achieve full spectrum dominance so that American and coalition forces can change the course of events in hours, minutes or even seconds. The environment provides physical and electronic distribution of Intelligence, Surveillance and Reconnaissance (ISR) data, processes, and systems." The DoD is building this new system with block upgrades. The current Block 10.2 upgrade [21] "integrates multiple intelligence systems into a single, worldwide network-centric-enterprise, enabling interoperability and improved collection and delivery of ISR data. DCGS web-based technologies will transform ISR into an integrated element of DoD Command and Control systems."

5. Leveraging Net-Centric Technologies

Most sensor platforms within the USAF have a limited number of radios that are primarily used for voice communications and navigation. The US Air Force Research Laboratory (AFRL) Information for Global Reach (IFGR) program has developed technologies that optimize the existing wireless communication infrastructure in support of standards-based Machine to Machine (M2M) connectivity. Air Combat Command (ACC) has made the decision to transition the IFGR capabilities onto Joint STARS. The instantiation is called the Interim Capability for Airborne Networking (ICAN) and has demonstrated the ability to send and receive timely, prioritized, secure information from the jet to the Combined Air and Space Operations and other ground sites on the Secret Internet Protocol Router Network (SIPRnet) in support of Desert Storm. This capability will improve the warfighters' effectiveness by enabling the use of standard Commercial-Off-The-Shelf (COTS) communications protocols over their existing radio assets as well as automatically managing the allocation of bandwidth based upon the priority of the mission and data to be transported.

The time is right to leverage current technologies to dynamically change air tasking orders (ATO) in near real time and allow for the dynamic management of sensors and communications on board a sensor platform. This will allow for instant images, target track information, and streaming video to be provided to the DIB/GIG and then e.g. to the special operation forces (SOF) or soldier in the field in less time than what is capable today. It will also allow for the distribution of ISR data to COIs in near real time thereby allowing planners to be more proactive than reactive to the changing environment.

Consider the following figure. An air tasking order (ATO) or a replanning ATO document would be developed and published at the command center and distributed via the DIB. This ATO would provide information of where and how to obtain ISR information but also where in the flight communications should be used to download the information. Once the assets are in flight and if a high priority ISR request occurs then a real time changing of the flight plan could immediately be published, assessed by all via the DIB/GIG and if approved the replanning could be sent to the airborne asset. The resultant ISR information would be sent to the DCGS then to the DIB/GIG and onto the command center. Then the information could be repackaged by the IMP for the soldier in the field based upon such constraints as communications, security, receiver characteristics, and bandwidth.

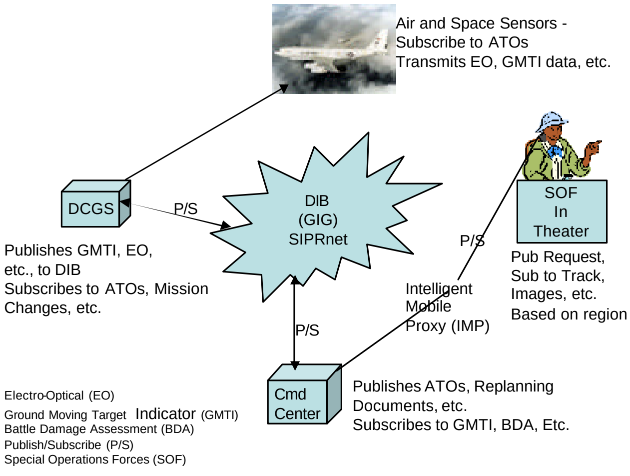

Figure 6 A Notional Net-Centric Scenario

Implementing such a system would involve extending and leveraging knowledge base processing and Semantic Web technologies in numerous areas. For the IMP program knowledge about multiple computing devices e.g. size, speed, memory, screen resolution, etc., bandwidths, security, document formats, and rules for processing and communicating with the ultimate user must be developed. Within the IPN and XG programs ontologies must be developed for heterogeneous sensors and communications devices to communicate between onboard and off board devices. In addition an intelligent knowledge base system must be developed that will manage heterogeneous sensors that can work cooperatively sharing the frequency spectrum without causing EM fratricide especially when the devices are like XG transceivers and radar waveform diversity systems. The system level approaches i.e. JSSEO and the DIB are very complex systems that will rely on ontologies and their embedded rules for their successes. Knowledge bases, data mining, and real time control are some of the areas that will be required in order for them to be successful.

6. Conclusions

Semantic Web technologies are valuable tools to help meet the challenges facing developers of intelligent information systems. Semantic Web technologies provide an additional layer of abstraction that will help in the development, maintenance, extensibility, and software reuse for complex intelligent information systems, allowing systems to evolve and change to meet dynamic conditions. Semantic Web technologies are being incorporated into applications that are not limited to the Internet. There are numerous issues that must be addressed within knowledge base engineering if we are going to manage communications and sensors in near real time using a net-centric Semantic Web approach.

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