# Sensor Exposure, Exploitation, and Experimentation Environment (SE4)

**Diane D. Buell, Francis J. Duff**
*The MITRE Corporation*
**John C. Goding**
*The MITRE Corporation*
**Michael Bankston, Tim McLaughlin, Steve Six, Scott Taylor, Sam Wootton**
*The MITRE Corporation*

**CONFERENCE PAPER**

As the resident space object population increases from new launches and events such as the COSMOS/IRIDIUM collision, the maintenance of high-level Space Situational Awareness (SSA) has become increasingly difficult. To maintain situational awareness of the changing environment, new systems and methods must be developed. The Sensor Exposure, Exploitation and Experimentation Environment (SE4) provides a platform to illustrate "The Art of the Possible" that shows the potential benefit of enriched sensor data collections and real-time data sharing. Through modeling and simulation, and a net-centric architecture, SE4 shows the added value of sharing data in real-time and exposing new types of sensor data.

The objective of SE4 is to develop an experimentation and innovation environment for sensor data exposure, composable sensor capabilities, reuse, and exploitation that accelerates the delivery of needed Command and Control, Intelligence, Surveillance, and Reconnaissance capabilities to the warfighter. Through modeling, simulation and rapid prototyping, the art of the possible for a fully-connected, net-centric space Command and Control (C2) and sensor enterprise can be demonstrated. This paper provides results that demonstrate the potential for faster cataloging of breakup events and additional event monitoring that are possible with data available today in the Space Surveillance Network (SSN). Demonstrating the art of the possible for the enterprise will guide net-centric requirements definition and facilitate discussions with stakeholder organizations on the Concept of Operations (CONOPS), policy, and Tactics, Techniques, and Procedures (TTP) evolution necessary to take full advantage of net-centric operations. SE4 aligns with direction from Secretary Gates and the Chairman Joint Chief of Staff that emphasizes the need to get the most out of our existing systems. Continuing to utilize SE4 will enable the enterprise by demonstrating the benefits of applying innovative net-centric concepts to SSA, resulting in efficient use of sensors, agile response to space events, and improved maintenance of the Space Catalog.

## 1. BACKGROUND

SE4 provides an experimentation environment where sensors and C2 systems are connected. In the fiscally-constrained environment we find ourselves in, it is important to utilize the existing SSA sensor resources as effectively and efficiently as possible. SE4 explores ways in which to do this. SE4 has the potential for demonstrating high value and operational impact by faster, better, and more complete decision making; and the ability to rapidly task/re-task sensors based on a better picture of a changing threat environment. Through implementation of SE4, capabilities and expertise will be incrementally developed to create a critical resource for manipulating and assessing the seam between sensor data and C2 capabilities, highlighting the best options for data exploitation to deliver new capabilities. The art-of-the possible for a net-centric enterprise will be demonstrated, which in turn will influence both users and their capability statements as future systems are upgraded and/or acquired.

SE4 leverages numerous reusable components within the architecture, which includes a Government Off-the-Shelf sensor-simulator, a MITRE-built component to warehouse and expose sensor data using Service-Oriented Architecture (SOA) techniques (i.e., web services), and a Joint Space Operations Center (JSpOC) SOA prototype for C2 processing and observation. Other ESC initiatives developed these components, and SE4 utilized them for additional applications. When stitched together with little-to-no adjustment from original design, concepts that can provide added benefit to the space domain are able to be explored.

Approved for Public Release: 11-3434. Distribution Unlimited

## 2. RESULTS

SE4 was developed incrementally in a series of development spirals. Spiral 1 demonstrated how net-centric sensors can be used to improve the cataloging of new objects after a large break-up event. This was accomplished by exposing Radar Cross Section (RCS) information dynamically so that sensors 'down the line' from the sensor initially seeing the break-up can plan to use their resources more efficiently, resulting in more observations collected in the early stages of the break-up event. Spiral 2 was used to show how net-centric data exposure can provide early indications of possible space events. In particular, this spiral made available to the enterprise information that is currently not being exploited. Spiral 3 is in the development stage at this time, but it aims to extend the first two spirals, by exposing Uncorrelated Track (UCT) and associated RCS data to the enterprise.

**SPIRAL 1: Net-Centric 'Handover'**

SE4 Spiral 1 successfully demonstrated numerous SSN improvements using the COSMOS/IRIDIUM collision data and the hypotheses:

- Net-centric 'handover' can greatly improve overall sensor and enterprise performance – a first step towards a 'Smart SSN'
- Sensors can schedule resources to collect high priority observations that would otherwise be missed by direct radar resources
- Sensors publish and subscribe to data for orbital debris or other unknown objects

Cooperative sharing of data, such as in a net-centric environment, can enhance event data collection. The potential improvement in coverage that could be provided in a net-centric SSN is shown in Fig. 1.

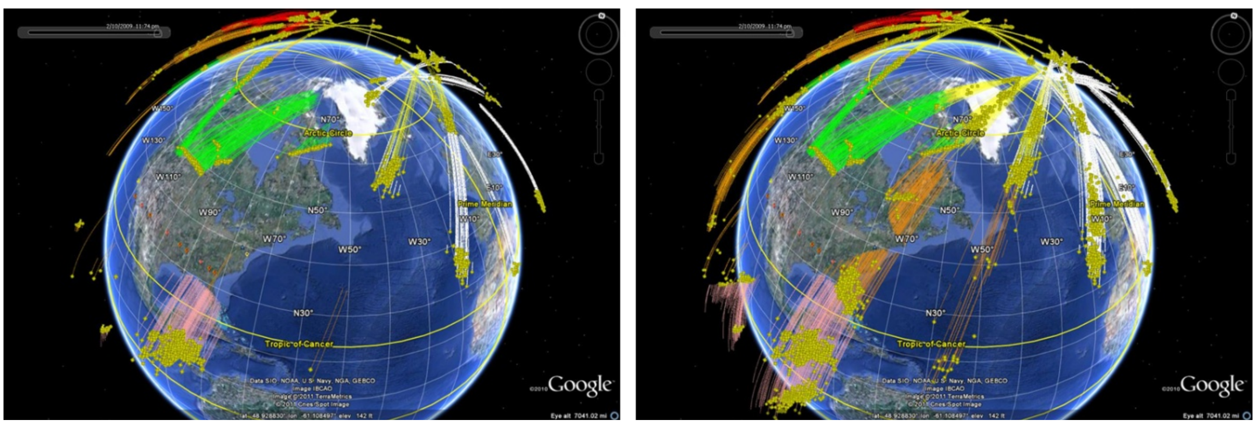


**Fig. 1. Example comparison of current coverage (left) and coverage given a net-centric SSN (right)**

The results of this spiral are illustrated in Fig. 2. In the left side of Fig. 2, the net-centric SSN collected 275 tracks per hour more than in the current SSN model. More tracks and additional orbit coverage improved the orbit determination process, decreasing the time to first element set from five to two hours, as shown in the right side of Fig. 2.

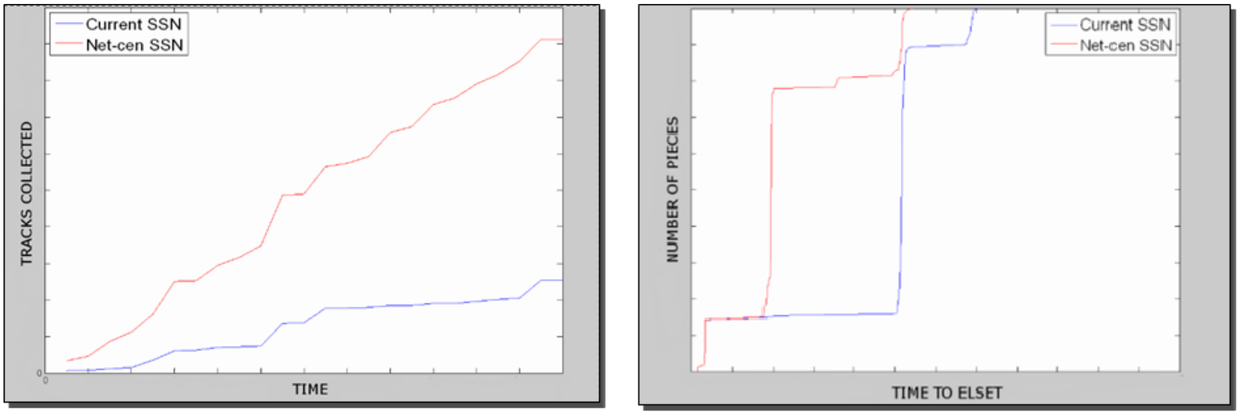


**Fig. 2. Spiral 1 Results: SSN track rate analysis (left) and Time to create an element set analysis (right) of Iridium Debris**

Concerning infrastructure, SE4 used Spiral 1 to develop the connectivity that would be used in the future spirals, specifically hosting a virtual image of the Joint Space Operations Center Mission Systems (JMS) and connecting it with Sensor Layer Information Service Environment (SLiSE).

**SPIRAL 2: Radar Fence Detection Exploitation**

SE4 spiral 2 demonstrated the potential improvements that could occur through the use of a net-centric SSN and exposing a small amount of additional information that is not available, in real-time, today. Revisit rates can be improved within the SSN by simply exposing and exploiting existing fence detection data from current SSN sensors. This radar fence detection data requires an additional data element, time off element set, to be exposed in addition to the information that is currently exposed with the Net-Centric Sensors and Data Sources (N-CSDS) Orbital Element Set message. Cooperative sharing of data within a net-centric SSN enhances fence detections, as shown in Fig. 3.

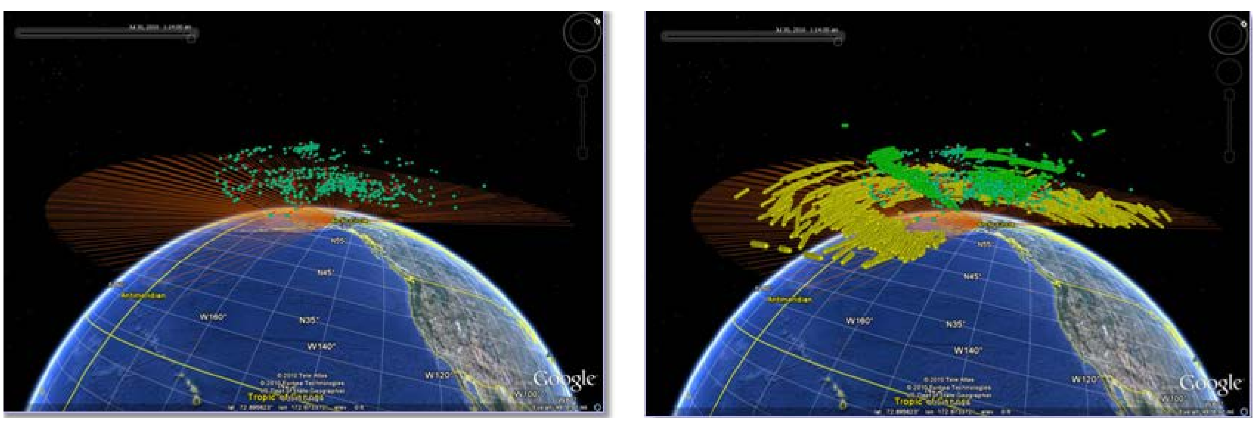


**Fig. 3. Example comparison of current fence detections (left) and fence detections given a net-centric SSN (right)**

By providing this information, the C2 operator receives a heads-up that an event may be unfolding, such as a maneuver, separation, or break-up. Fig. 4 depicts the resulting analysis of utilizing net-centric fence detections. Specifically, the average change in maximum gap time is reduced by seven hours over the gap times resulting from the current SSN implementation.

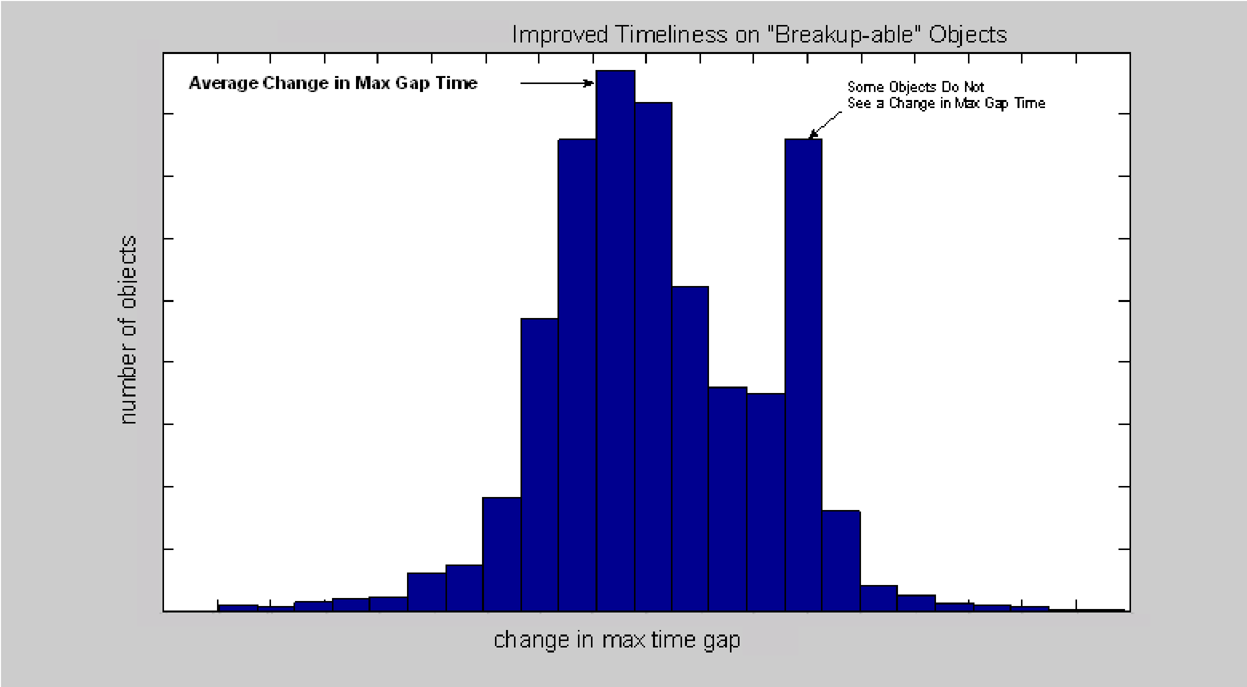


**Fig. 4. Spiral 2 Results: Improved timeliness on "breakupable" objects**

**Future Spiral 3**

Spiral 3 is getting underway now and includes both breakup and separation scenarios. Spiral 3 will assess the technical feasibility and operational benefits of exposing UCT and associated RCS data, and communicating this data net centrically using N-CSDS observation messages to expedite the correlation of UCTs and early detection of satellite separations. The breakup scenario will exercise an end-to-end thread from simulated legacy sensors (via Architecture Trades and Sensor Assessment Tool (ATSAT)) to a RCS-augmented Multiple Hypothesis Tracking (MHT) service processing, to display on the JMS User Defined Operational Picture (UDOP). Note that the service could be resident anywhere on the smart SSN, making the data available to all appropriate participants, as well as the JSpOC, and demonstrating improvements in the correlation of UCTs across the SSN. Spiral 3 will demonstrate that the exposure of RCS and UCT data in real-time enables new services like MHT to expedite the association/ correlation process, leading to an improved space catalog. The separation scenario will focus on the improved detection capabilities of future SSN sensors that, when combined with RCS-enhanced MHT processing and handoff to down-line sensors, will allow detection of satellite separations that otherwise would have gone unnoticed.

**Impacts**

SE4 demonstrates the benefits of applying innovative net-centric concepts to SSA; namely, more agile responses to space events; improved maintenance of the Space Catalog; and more efficient use of sensors. SE4 demonstrates how to use experimentation to accelerate CONOPS, TTP, and requirements changes. Collaboration with warfighters, user commands, and Programs of Record (PoR) is essential to realize these changes. By utilizing existing expertise and tools, improvements to current capabilities can be showcased with minimal cost. The experimentation can thereby stimulate technical and CONOPS discussions with the warfighter and acquisition communities, which is needed to foster change and adopt innovation. We have found that the combination of Modeling and Simulation results, data analysis, and prototype demonstration is a powerful way to showcase “art-of-the-possible” SSA enterprise operations.

## 3. TECHNICAL ARCHITECTURE

SE4 is comprised of three main components: 1) the data source, 2) the data warehouse and exposer, and 3) the user interface. Fig. 5 shows these components as they are currently implemented in SE4, and each of these will be described in more detail in this section. The first component is the data source. In the current implementation of

SE4, the data source is a simulated legacy sensor, represented by the ATSAT. This simulated sensor provides data to a software implementation of a sidecar, which translates the data from ATSAT's data format (B3) to an eXtensible Markup Language (XML) format based on the emerging N-CSDS data standard. N-CSDS is the emerging common schema for space surveillance sensor data. This data is then made available to the enterprise via a Transmission Control Protocol/Internet Protocal (TCP/IP) server. The data warehouse and exposer, or in this case the SLiSE, listens to this TCP port and accepts the data as it is made available. This information is then ingested into the data warehouse, and exposed to the rest of the data-consuming community and user interfaces, specifically JMS within SE4. It should be noted here that SE4 has been developed at three MITRE locations (Massachusetts, New York and Colorado) and connected by a MITRE internal network to ensure security of information.

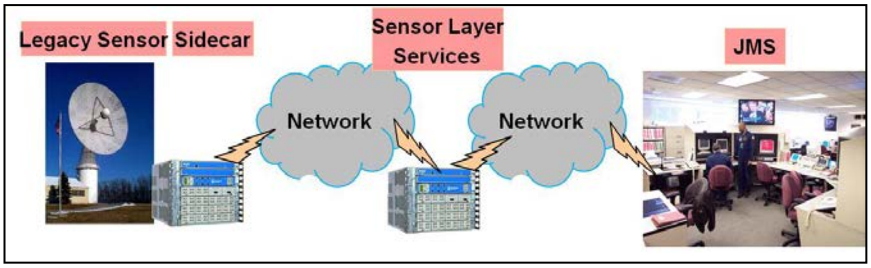


Fig. 5. SE4 Architecture Overview

**ATSAT Modeling and Simulation**

ATSAT (Fig. 6) uses the same sensor models as currently used by AFSPC. These sensor models are used to generate simulated sensor data and, with small modifications, can provide more information than is currently transmitted to the C2 center. The ATSAT observation data is made available via a flat file, in sensor legacy B3 data format. This data format is the current legacy format for sensor data. To simulate the process of data being made available to the enterprise, the ATSAT-simulated sensor data is parsed and converted into an N-CSDS metric observation messages. For Spiral 2, we extended the current N-CSDS Orbital Element set message into a new message we call a "FenceDetectionMessage". This new "FenceDetectionMessage" was derived from sensor data which is currently unexposed. We basically added an additional field, tag named "TimeOffElset," to the Orbital Element Set message. This new field provides a value for indicating if a satellite is off its current expected position, as compared to its expected arrival time, all of which is based on its ephemeris. This value is used to generate warnings for satellites that may have changed their orbits due to planned maneuvers or natural forces.

The data is made available to the network via a server/client configuration. The server broadcasts the sensor messages to the clients using TCP/IP connections. The sensor information is provided via a stream until all messages are sent. For the sake of this demonstration, the TCP server can be considered a sensor sidecar, and the client (SLiSE) is part of the sensor layer services software. Currently, the simulated sidecar server is located at the MITRE facility in Bedford, Massachusetts, and the client side is located at MITRE Rome, New York.

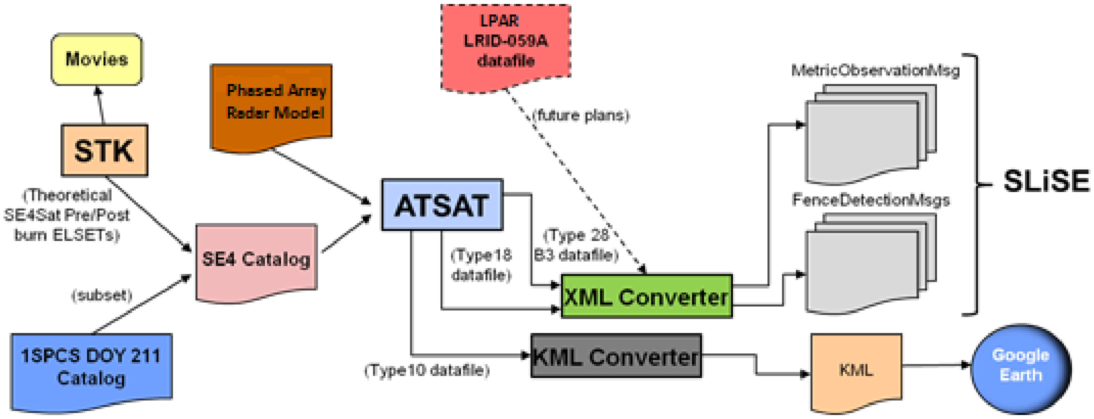


Fig. 6. ATSAT Modeling and Simulation Implementation

**SLiSE**

The SLiSE is the data warehouse and exposure tool currently hosted in Rome, New York. A SLiSE plug-in was generated as a TCP client. This client listens to the TCP server stream that is described above in the ATSAT collection. The information is downloaded onto the computer hosting the SLiSE client software. Once a fence detection message is received, the SLiSE PUT data service is called to upload the file into the SLiSE warehouse and makes the data available to the rest of the enterprise. The SLiSE architecture diagram is shown in Fig. 7. The mirrored view of internal layers and services depicts SE4's use of the SLiSE services in both consumer and producer roles.

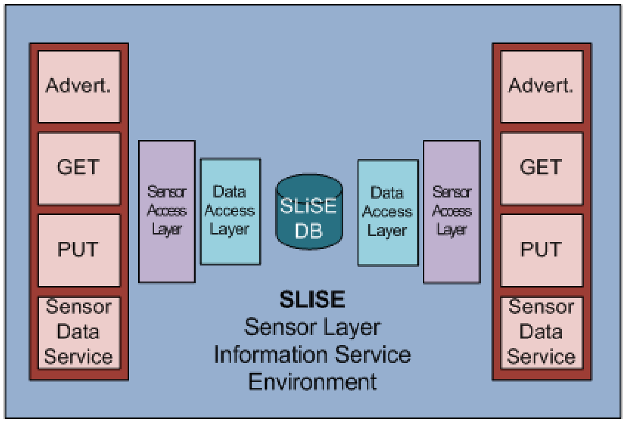


**Fig. 7. SLiSE simplified architecture diagram**

When the PUT data service is called, an additional service is utilized. This service is called the Sensor Data Service, and it handles metadata processing of the uploaded files. This service runs extraction tools to read file metadata if necessary, or in the case of XML, simply parses the file to extract the SLiSE exposure data. Exposure data can be thought of as information that is available in Really Simple Syndication (RSS) feeds, or more specifically, less commonly used GeoRSS feeds. Information is intended to be minimalistic to ensure usability across data types and processing levels. Each file processed by SLiSE includes sensor name, longitude, latitude, datatype, intelligence type, processing level, the time when SLiSE processed the file, the time when the data was collected, and an additional information field, which can be used for datatype specific metadata, such as time off element set value or altitude.

The "RSS" information is provided via the Advertisement Service. The client requests a specific subset of information, for instance all data of the fence detection XML type, for a particular time span. This will provide the client calling the service with a number of "RSS" objects. Each object also includes the database information so that the raw file can be retrieved, if the client is interested. Using the GET data service, the raw file is obtained for user processing. By first providing a small RSS-like message, and then raw files on demand, the user can selectively obtain data and avoid being overwhelmed with too much information.

**JMS**

The client and user interface is a prototype version of JMS. JMS, the PoR for the JSpOC, is the C2 system that processes the SSN sensor data. JMS provides a SOA infrastructure and a common space UDOP. SE4 hosts a virtual image of JMS.

The ground-based SSN, simulated by the SE4 infrastructure and the SLiSE Advertisement service, notifies the SSN that new sensor data is available for processing and analysis. The SLiSE service calls are handled through the JMS Application Server. A request to use the service calls a proxy service, which is a copy of the original SLiSE service hosted in Rome. The proxy then forwards the service request on to the equivalent Rome service. When the advertisement object is received as a response to the Advertisement service, the detection is processed and displayed on the National Aeronautics and Space Administration (NASA) Worldwind image within the UDOP, and the time off element set values read. If the value is over a designated threshold, an alert is generated that provides the user operator with knowledge that a potential natural or manmade maneuver has occurred. The alert is represented by an exclamation mark next to the satellite icon in NASA Worldwind, and corresponding text is displayed in the box below the globe image. The JMS UDOP, as implemented in SE4, is shown in Fig. 8.

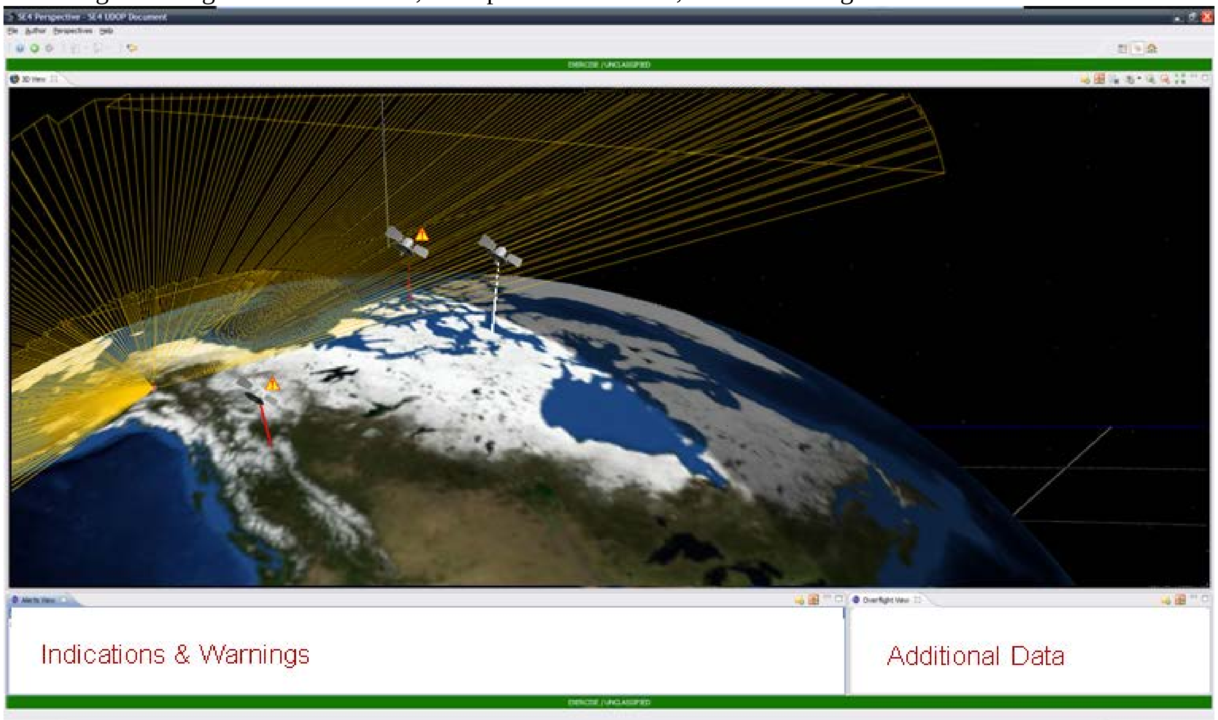


**Fig. 8. JMS UDOP as implemented in SE4 displaying Fence Detections, denoted by satellite icon**

**SE4 Prototype**

A high level representation of the SE4 architecture is shown in Fig. 9. The data source is located on the far left. In the blue box, in the middle of the architecture is SLiSE which provides service exposure for uploading and downloading data. On the right-hand side of the image, is the representative implemented JMS image, with interface to the user display.

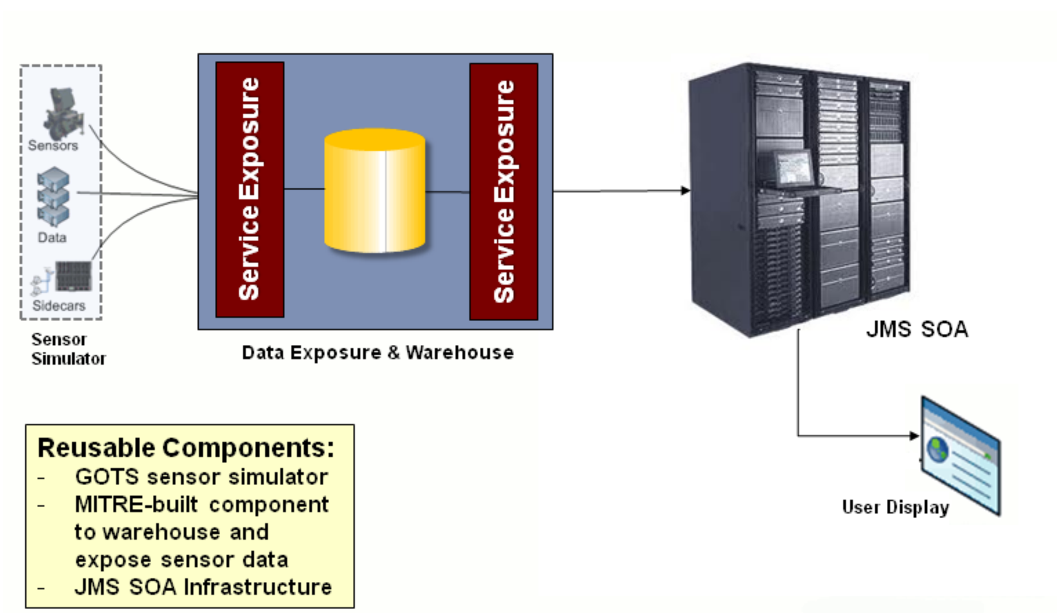


**Fig. 9. SE4 Architecture**

The data source for SE4 is the simulated sensor, ATSAT, and software implemented sidecar. In this diagram, the data source is simulated sensor data, as both sensors and sidecars denote live capability that could be made possible in the future. ATSAT and the simulated sidecar are located in Bedford, Massachusetts.

SLiSE is the data warehouse and exposure tool. For this reason, it is both a data consumer and provider. It first consumes the source data from the simulated software sidecar. SLiSE provides the data to the enterprise, more specifically, JMS. To upload the data into the warehouse, denoted by the left side of the blue SLiSE box, SLiSE uses the PUT data service and the Sensor Data Service. The internals of SLiSE are utilized to process the data and store it in raw form, and exposed metadata form in a Structured Query Language database in Rome, New York. This information is then retrieved by JMS utilizing the Advertisement Service, and GET Data service, denoted on the diagram by the right side of the blue box.

JMS is the net-centric enterprise data consumer and user interface within SE4. Typical data communication begins with the JMS UDOP interacting with the Early Indications and Warnings (I&W) service, which has been added to the JMS Application Server. The Early I&W Alert service sends a request for SLiSE data advertisements that are of type fence detection message that have occurred since the last update was received by the Early I&W Alert service. This request is made in Colorado Springs, Colorado and is sent to Rome, New York where it is processed by SLiSE. SLiSE replies with the requested information. If the user then wants more information than the advertisement provides, they would then request the full raw data file from SLiSE via the GET data service.

## 4. SUMMARY

SE4 demonstrates the possible operational improvements to be realized by simply making the SSN-C2 architecture net-centric, and ensuring information can reach its users. As was shown with the added exposure of fence detection data, it is important to make all data available to the users, as new techniques may evolve to use the new information. By simply making the data readily available, SE4 was able to showcase a scenario where more tracks, shorter times to ELSET 1, and improved event detection can be achieved. As SE4 moves forward, data exposure and accessibility will be emphasized through the use of uncorrelated track and RCS data.

SE4 also showed that making use of currently developed software and prototypes, with minimal modifications, allows for the quick stand-up of additional capabilities, while staying within fiscal constraints. SE4 is a geographically diverse simulation environment that exemplifies how information can be shared through an entire enterprise to achieve new or improved capabilities that enhance situational awareness.

We continue to demonstrate SE4 results to the SSA community to encourage innovative thinking that will lead to changes in CONOPS, policy, and/or TTP. In this way, currently unexploited data from SSN sensors can be utilized as effectively and efficiently as possible, resulting in increased operational capability with minimal materiel investment.

## 5. ABBREVIATIONS AND ACRONYMS

ATSAT – Architecture Trades and Sensor Assessment Tool

C2 – Command and Control
CONOPS – Concept of Operations

I&W – Indications and Warnings

JMS – Joint Space Operations Center (JSpOC) Mission Systems
JSpOC – Joint Space Operations Center

MHT – Multiple Hypothesis Tracking

N-CSDS – Net-Centric Sensors and Data Sources
NASA – National Aeronautics and Space Administration

PoR – Programs of Record

RCS – Radar Cross Section
RSS – Really Simple Syndication

SE4 – Sensor Exposure, Exploitation and Experimentation Environment
SLiSE – Sensor Layer Information Service Environment
SOA – Service-Oriented Architecture
SSA – Space Situational Awareness
SSN – Space Surveillance Network

TCP/IP – Transmission Control Protocol/Internet Protocol
TTP – Tactics, Techniques, and Procedures

UCT – Uncorrelated Track
UDOP – User Defined Operation Picture

XML – eXtensible Markup Language