Clients of Space Situational Awareness (SSA) Net-Ready Data

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CONFERENCE PAPER

1. ABSTRACT SUMMARY

Multiple Net-Centric approaches have been developed to expose optical and radar sensor data. Client applications have been developed to ingest and process this data by the National Air and Space Intelligence Center (NASIC) and the Joint Space Operations Center (JSpOC) Mission System (JMS). Data flows and formats used that integrate these Net-Centric approaches with JMS and NASIC will be presented. Example data collected and examples of improved Space Situation Awareness (SSA) benefits will be discussed. Potential future improvements to increase the precision of the Space Object Identification (SOI) processing algorithm will be addressed. Specifics regarding the process to gain access to the Net-Centric Sensors and Data Sources (N-CSDS) Ground Based Electro-Optical Deep Space Surveillance (GEODSS) sensor data in near real time will be identified.

2. NET-CENTRIC DATA SOURCES

Achieving Space Situational Awareness requires timely information regarding all ground nodes/infrastructure, links and on-orbit assets required to conduct space operations, as well as the hazardous debris environment. The number of near-earth and deep-space satellites has been increasing as space faring nations increase their capabilities and as new nations enter space. This has significantly increased the number of space related ground stations, communication links, and Resident Space Objects (RSOs).

Various techniques have been developed for net-centric exposure of SSA data to include *Net-Centric Sensors and Data Sources (N-CSDS) Ground-based Electro Optical Deep Space Surveillance (GEODSS) Sidecar* [1], Communications Processing System (CPS) Space Service Oriented Architecture (SOA) Server (CS^3) and *Extended Space Sensors Architecture (ESSA) ACTD* [2].

N-CSDS GEODSS Sidecar

The N-CSDS GEODSS Sidecar defines one approach to make data accessible. The Sidecar concept is to publish data in Near-Real Time (NRT) via the Net-Centric Enterprise Services (NCES) interface and provide Request/Response queries via Web Services. A sidecar has been defined as an on-line, computer processing system that net-centrically exposes data from a host system in a non-interfering manner that effectively decouples the sidecar processing and communication paths from the host system operational string. The initial N-CSDS Sidecar was developed in support of the Space Surveillance Network (SSN). However, the N-CSDS Sidecar can be adapted to support any data source. The mission of the sidecar is to provide a net-centric, one or two-way path for access to the data of a particular data source and to provide input data. The N-CSDS Sidecar has been deployed to the GEODSS sensor located in Socorro, New Mexico and deployments are in progress to the Maui, HI and Diego Garcia GEODSS facilities. An overview of the N-CSDS system is illustrated in Fig. 1. The GEODSS sensor data exposed using the N-CSDS GEODSS Sidecar can be obtained by following the account request instructions documented in the N-CSDS Sidecar Net-Centric Services Users Guide.

ESSA Sidecar

Massachusetts Institute of Technology (MIT)/Lincoln Laboratories (LL) developed a Net-Centric approach to expose SSA data under the Extended Space Sensors Architecture (ESSA) Advanced Concept Technology Demonstration (ACTD). The ESSA ACTD sidecar has been deployed to both optical and radar sensors providing Space Situational Awareness data. This information is published to NCES. Clients subscribing to topics receive the data in near real time.

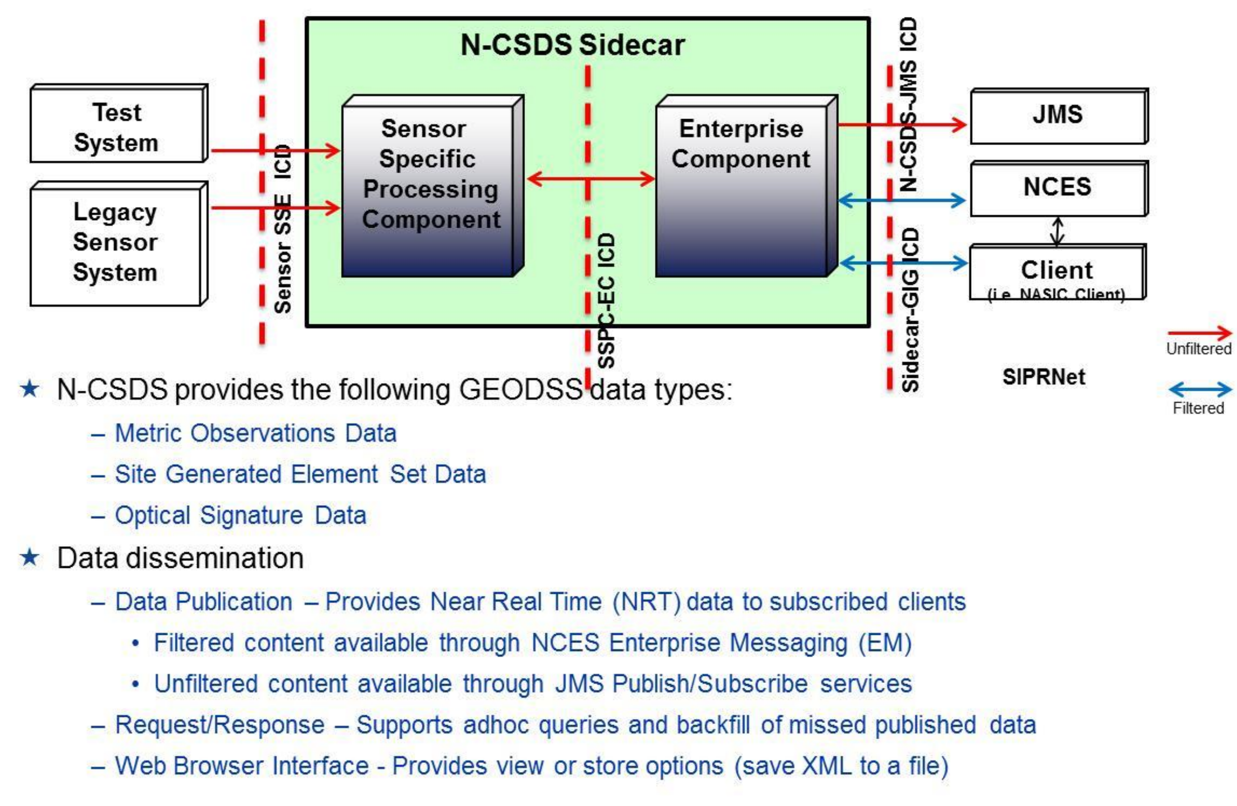

Fig. 1 Net-Centric Sensors and Data Sources (N-CSDS) Overview

Communications Processing System (CPS) Space Service Oriented Architecture (SOA) Server (CS3)

The purpose of the Communications Processing System (CPS) Space Service Oriented Architecture (SOA) Server (CS^3) system is to make CPS data available to clients in a common, eXtensible Markup Language (XML) schema format. The CPS data includes all space data sent to and from Space Defense Operations Center (SPADOC) and the CS^3 makes such data available to the consumer clients via Publication and Query Services.

The capability also exists for clients to send data in an XML format for translation and forwarding to CPS.

Fig. 2 illustrates the external interfaces related to CS^3. Several legacy sources and SSN sensors provide data to CPS at Cheyenne Mountain Air Force Station (CMAFS). Once CPS receives these messages, it sends the messages through a dedicated TCP/IP link to CS^3 at Vandenberg AFB (VAFB).

CS^3 receives these messages and filters out which messages to process based on the Message Format Number (MFN). The filtered messages are translated into a common, XML schema format. The XML messages are then published to a Java Messaging Service (JMS) for subscribed clients to receive in near real-time and stored in the CS^3 database for future retrieval via Hypertext Transfer Protocol (HTTP) web services.

The following are the interface capabilities provided from the CS3 to the client applications:

a. Data Publication Service for publishing XML formatted Space data to client subscribers in near real-time.

b. Query Service for clients requesting historical data stored in the CS3 database.

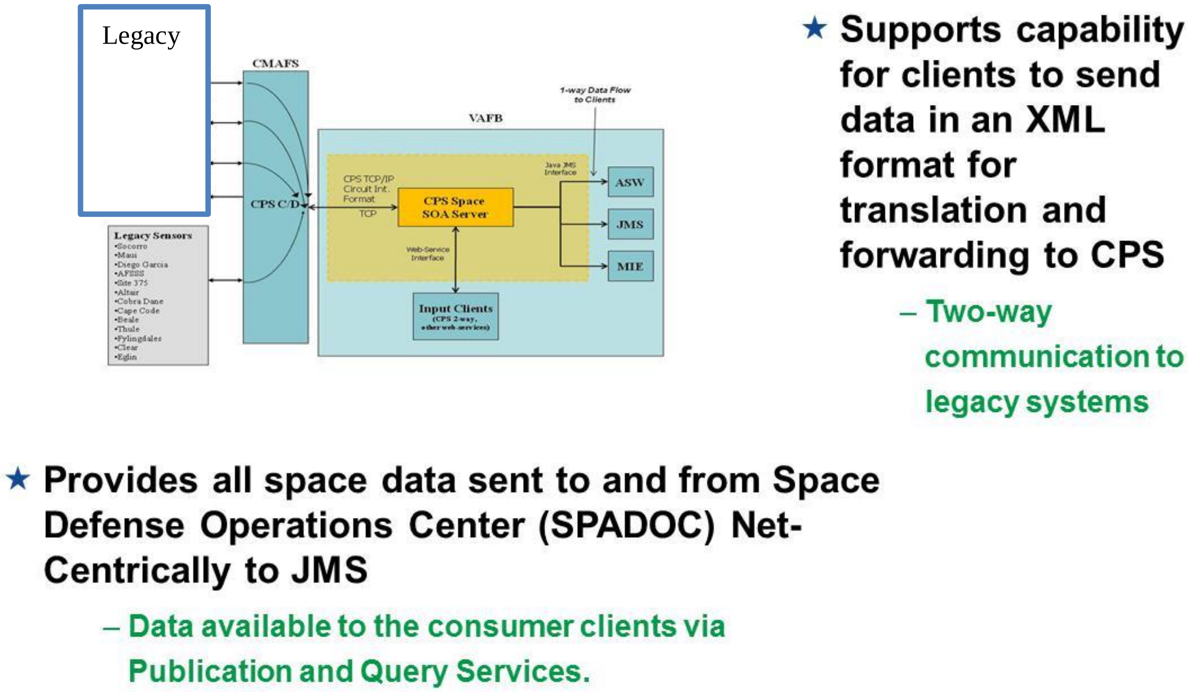

Fig. 2 CPS Space SOA Server Overview

3. NET-CENTRIC CLIENTS

Net-centric data exposure alone will not provide mission utility. Rather, net-centric data exposure enables the creation of client applications that can provide increased capabilities and situational understanding. The net-centric data exposure efforts offer clients the ability to receive the data in near-real time through publish/subscribe capabilities. In many cases this was accomplished through the Enterprise Message capability provided by NCES. Various clients have been developed that consumes the SSA data exposed net-centric to include Joint Space Operations Center (JSpOC) Mission System (JMS) Sidecar Client and NASIC Message Client.

NASIC Client

The NASIC Client is designed to subscribe to Enterprise Messaging (EM) SSA topics. A PKI certificate is used to authenticate and authorize access to the data. It receives the data in eXtensible Markup Language (XML) format. A sequence number within each message is examined to determine if any data was not received in the Near-Real Time (NRT) data stream to the client. The NASIC client invokes a backfill web service to marshal any missed messages. The NASIC Client converts the optical signature data into either the legacy GE06 format or the Electro Optical Space Situational Awareness (EOSSA) format. The optical signature data is then made available to NASIC's data processing tools. The EOSSA format is built upon the NASA FITS binary file format. The EOSSA format supports greater data precision and provides additional data fields not previously available with the GE06 format. The NASIC client includes a full Graphical User Interface (GUI) that allows a user to view message statistics and manage connections/subscriptions to EM.

The NASIC Client stores all data received as shown in the directory structure illustrated in Fig. 3. The received messages files are organized into directories based on their respective data type. The File name includes the message's sequential ID number. These raw files can be opened in any application that supports XML (e.g. Firefox web browser). The EOSSA and GE06 files created by the NASIC client are written into separate directories and provided to existing NASIC data processing flows. The NASIC client periodically purges data older than a configurable age to maintain file system integrity.

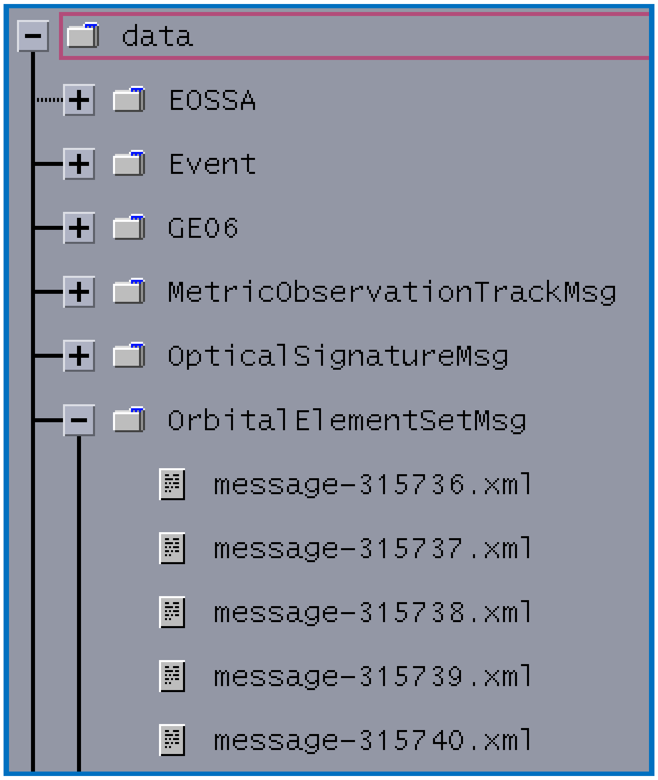

Fig. 3 NASIC Client Data Output

Optical Signature data benefits are illustrated in the contrived data found in Fig. 4. The Optical Signature message is comprised mainly of a collection of visual magnitude values for a given object over a given time period. The data provided using the net-centric data model provides greater precision than the legacy message (GE06). This improved precision provides greater insight to characterize RSOs.

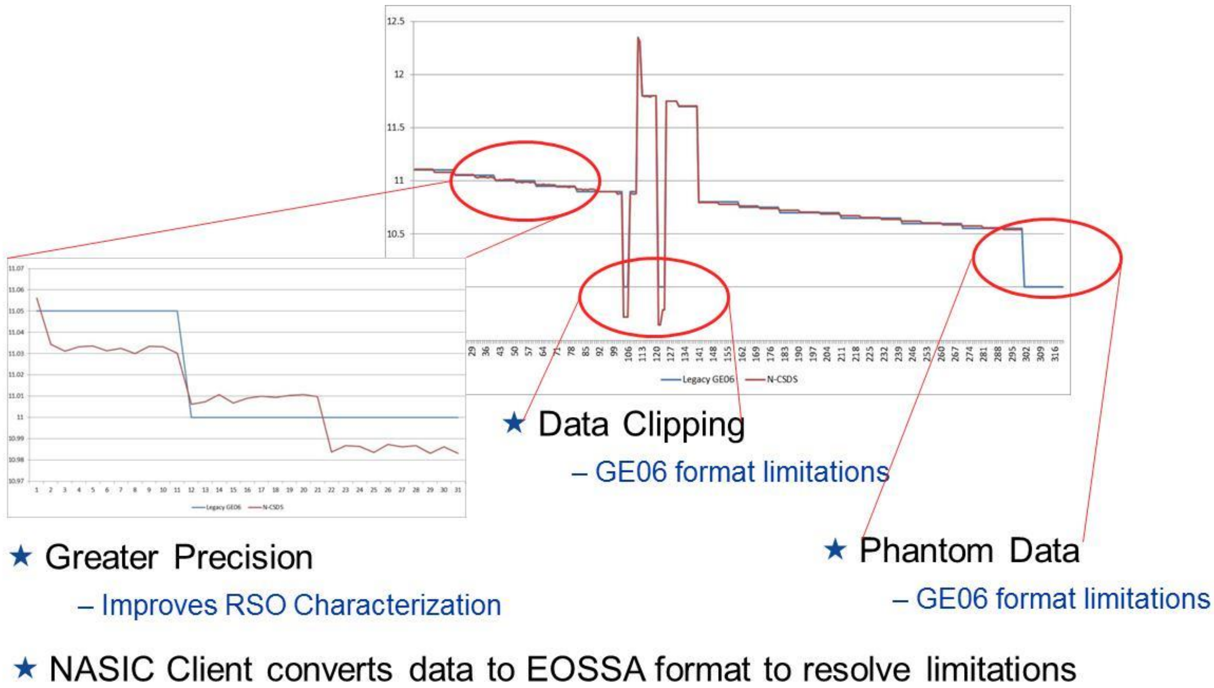

Fig. 4 Optical Signature Data Benefits (Notional Example)

JMS Sidecar Client

The JSpOC Mission System (JMS) Sidecar Client is designed to receive the N-CSDS Sidecar metric observations and makes the data available to the JMS catalog maintenance capabilities. It is scheduled for deployment into JMS Service Pack 9 (SP9) and will leverage the existing Communication Processing System (CPS) Space SOA Server (CS^3) as its host.

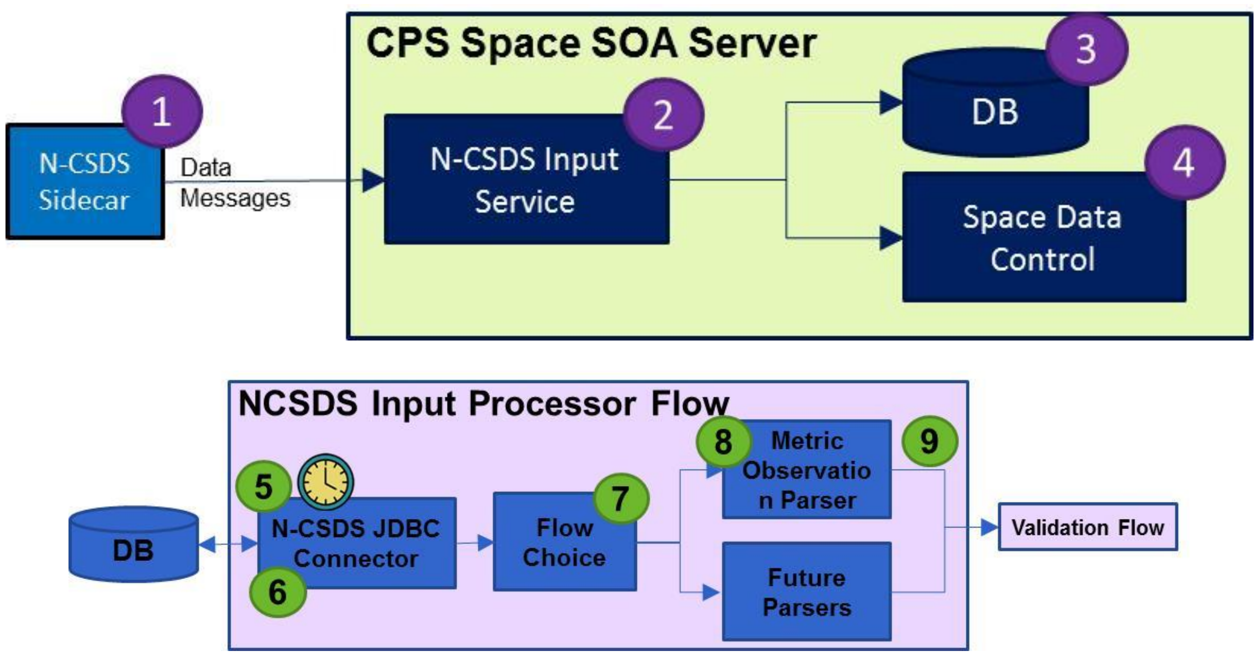

Fig. 5 JMS Sidecar Client Metric Observation Flow

The JMS Sidecar Client Metric Observation data flow is illustrated in Fig. 5. It is initiated when the N-CSDS Sidecar sends unfiltered metric observation data to the JMS Sidecar Client. The JMS Sidecar Client uses the JMS Notification message schema to define a web service endpoint that is hosted in CS^3 JBoss Application Server. The N-CSDS Input Service validates and verifies the incoming message complies with the defined interface. All validated messages are assigned a unique identifier and assigned a message format based on the originating system and message type. The message along with key attributes like arrival time and source are stored in the database using the unique identifier for later retrieval. The Space Data Control component records the receipt time of the message to track the status of the interface to this data source. The JDBC Connector periodically polls for newly received messages and retrieves the new messages for translation. The assigned message format is used to determine the proper parsing class within the JMS Sidecar Client that will transform the N-CSDS Metric Observation Track message into the JMS format. The validation flow ensures the message is properly formatted for JMS. The information is stored to provide query capabilities of the metric observation in JMS format to other JMS applications. The validation flow publishes the N-CSDS Sidecar metric observations in Enterprise Data Model (EDM) XML format to the observation processing flow within JMS.

An example of the Optical Metric Observation data provided by the N-CSDS GEODSS Sidecar is illustrated in Fig. 6. This format contains additional fields that are not currently provided in the legacy catalog maintenance flows that can be used to improve Space Situational Awareness (SSA). For example, the visual magnitude and solar phase angle, currently not provided in the legacy message, can be leveraged in the association of observations to existing catalog items to reduce cross tagging to improve catalog maintenance. Understanding the range to the target, currently not provided in the legacy message, provides the data necessary to convert between absolute and observed visual magnitude providing additional information to correlate the observation with known Resident Space Objects (RSO).

The Declination and Right Ascension values provided in the N-CSDS Optical Metric Observation message provide greater precision than the legacy messages. This is because the legacy message format has fixed length data fields and the XML allows for the full precision provided by the sensor. Providing this greater precision will improve the accuracy of the catalog's position information.

Differences in processing features between the N-CSDS GEODSS Sidecar and the legacy processing of metric observation data provide additional benefits. The N-CSDS sidecar groups the observations into tracks, while the legacy processing transmits only the observation and requires the formation into tracks to be done at the JSpOC. Since the sensor is aware that it is continuously observing the same object, the sensor's data will be much more accurate in determining tracks than reconstructing the event in software.

Legacy point to point communication channels have bandwidth constraints resulting in restrictions in the quantity of data being exchanged. Policies such as the minimum number of observation used in a track have been established that ensure all data transmitted will be used in processing. This limitation is also addressed procedurally by transmitting only data requested. This results in additional supplemental data not being considered when creating the current situational picture. The N-CSDS GEODSS Sidecar is designed to provide all the observations and allow the client to determine the usefulness of the data.

```xml
<soap:Envelope xmlns:soap="http://schemas.xmlsoap.org/soap/envelope/">
  <soap:Body>
    <ssmo:MetricObservationTrackResponse wcommon:requestIDRef="urn:uuid:c7035c40-0f3f-11e4-a3b5-9250569f28ab
      <ssmo:MetricObservationTrackMsgCollection ism:DESVersion="9" ism:classification="U" ism:compliesWith="DoD5230.
        <ctyp:MetricObservationTrackMsg ism:DESVersion="9" ism:classification="U" ism:compliesWith="DoD5230.24" ism:c
          <ctyp:CommonHeader>
            <ctyp:SenderInfo messageID="urn:ncsds:metricobservationtrackmsg:socorro_geodss_sc:176719"/>
            <ctyp:SourceID codespace="http://www.C2SSA.gov/C2SSADomain/Common/CodeList/SiteID/2.0.0" ism:classifi
            <ctyp:MsgCreationTime>2014-07-14T15:42:48.75Z</ctyp:MsgCreationTime>
            <ctyp:MsgContentPriority>routine</ctyp:MsgContentPriority>
            <ctyp:DataEnvironmentIndicator>test</ctyp:DataEnvironmentIndicator>
          </ctyp:CommonHeader>
          <ctyp:MetricObservationTrackCollection>
            <ctyp:MetricObservationTrack ism:classification="U" ism:ownerProducer="USA" obsCount="1" passIDRef="226
              <ctyp:SatelliteNumber>20005</ctyp:SatelliteNumber>
              <ctyp:SensorID codespace="http://www.C2SSA.gov/C2SSADomain/Common/CodeList/SensorID" ism:classifi
              <ctyp:StartTime>2014-07-14T01:33:14.111000Z</ctyp:StartTime>
              <ctyp:StopTime>2014-07-14T01:33:14.111000Z</ctyp:StopTime>
              <ctyp:MetricObservationCollection>
                <ctyp:MetricObservation>
                  <ctyp:Time>2014-07-14T01:33:14.111000Z</ctyp:Time>
                  <ctyp:VisualMagnitudeData>
                    <ctyp:AbsoluteVisualMagnitude uom="Mv">2.41671</ctyp:AbsoluteVisualMagnitude>
                    <ctyp:AssumedRangeToTarget uom="km">10019.17</ctyp:AssumedRangeToTarget>
                    <ctyp:SignedSolarPhaseAngle uom="rad">-0.05480323</ctyp:SignedSolarPhaseAngle>
                    <ctyp:ObservedVisualMagnitude uom="Mv">-2.487542</ctyp:ObservedVisualMagnitude>
                  </ctyp:VisualMagnitudeData>
                  <ctyp:Type5>
                    <ctyp:YearOfEquinox>ob_0_Jan_2000</ctyp:YearOfEquinox>
                    <ctyp:Declination uom="rad">1.16651445</ctyp:Declination>
                    <ctyp:RightAscension uom="rad">2.38518276</ctyp:RightAscension>
                  </ctyp:Type5>
                </ctyp:MetricObservation>
              </ctyp:MetricObservationCollection>
            </ctyp:MetricObservationTrack>
          </ctyp:MetricObservationTrackCollection>
        </ctyp:MetricObservationTrackMsg>
      </ssmo:MetricObservationTrackMsgCollection>
    </ssmo:MetricObservationTrackResponse>
  </soap:Body>
</soap:Envelope>
```


Fig. 6 Metric Observation Sample Data

Advanced Space Mission Utility Experiment

The Advanced Space Mission Utility (ASMU) experiment demonstrates another client application and it was conducted to investigate opportunities and challenges in performing cross-sensor operations via horizontal integration and is illustrated in Fig. 7. The ASMU experiment included electro-optical, laser, and radar test facilities with Lockheed Martin developed Intelligent Space (iSpace) Command and Control (C2) and mission data processing. The experiment demonstrated sensor tipping/queuing, rapid target identification, continuous track custody, automated threat assessments, distributed data fusion, and RSO fingerprint creation. Data exposed net-centrically enabled the ASMU experiment and Big Data concepts were used to provide mission utility.

The ASMU experiment leveraged multiple data sources that have been exposed net-centrically and Big Data concepts to perform intelligent catalog maintenance and continuous conjunction assessment. It uses a rule-base analysis of space events to perform a threat assessment and provide automated forensic and predictive threat analysis. It supports dynamic tasking of both conventional and non-traditional sensors. It utilizes multiple best of bread astrodynamic algorithms, including advanced UCT processing to address the ever increasing catalog maintenance size. iSpace is a prime example of how net-centric data sources enable client applications leveraging Big Data concepts to provide mission utility.

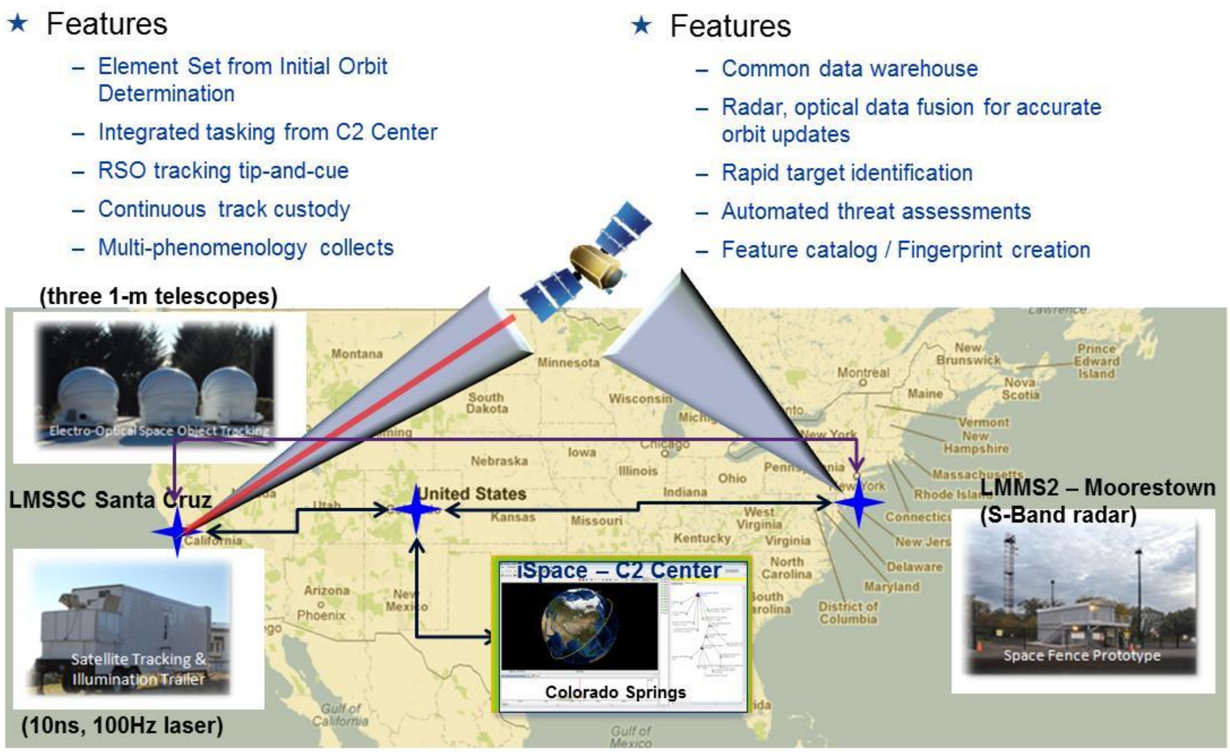

Fig. 7 Metric Observation Sample Data

The ASMU experiment required the initial orbit determination information to be provided net-centrically. An example of the N-CSDS GEODSS element set is illustrated in Fig. 8. This data structure provides greater precision than the legacy messages and facilitates sensor to sensor tipping and queuing.

Existing data structures limit the precision of the information being exchanged and limit the precision of key information computed such as the exact location of an RSO at a given time. This can be seen with the Two-Line Element (TLE) set. This data structure captures the orbital parameters of an RSO in two 80 character records. This legacy format, circa 1960, was created to accommodate the 80 character card readers used by mainframe computers and has persisted to this day to accommodate existing software that is dependent upon the data structure. Since each data field is constrained to specific character locations within the TLE, the data structure is not capable of expressing increased precision for any of the data fields. Similar limitations exist in other key SSA data structures caused by legacy formats.

```xml
<soap:Envelope xmlns:soap="http://schemas.xmlsoap.org/soap/envelope/">
  <soap:Body>
    <ssel:ElementSetResponse wcommon:requestIDRef="urn:uuid:36c8ec00-0f38-11e4-a3b5-9250569f28ab" xmlns:
      <ssel:OrbitalElementSetMsgCollection ism:DESVersion="9" ism:classification="U" ism:compliesWith="DoD5230.24
        <nsc:OrbitalElementSetMsg ism:DESVersion="9" ism:classification="U" ism:compliesWith="DoD5230.24" ism:cr
          <ctyp:CommonHeader>
            <ctyp:SenderInfo messageID="urn:uuid:36c8ec00-0f38-11e4-a3b5-9250569f28ab"/>
            <ctyp:SourceID codespace="http://www.C2SSA.gov/C2SSADomain/Common/CodeList/SiteID/2.0.0" ism:cl
            <ctyp:MsgCreationTime>2014-07-19T11:31:24.198Z</ctyp:MsgCreationTime>
            <ctyp:MsgContentPriority>routine</ctyp:MsgContentPriority>
            <ctyp:DataEnvironmentIndicator>real</ctyp:DataEnvironmentIndicator>
          </ctyp:CommonHeader>
          <nsc:OrbitalElementSetCollection>
            <ntyp:OrbitalElementSet ism:classification="U" ism:ownerProducer="USA">
              <ctyp:SatelliteNumber>10012</ctyp:SatelliteNumber>
              <ctyp:OrbitalElements>
                <ctyp:ElementSetNumber>29</ctyp:ElementSetNumber>
                <ctyp:Epoch>2014-07-16T02:41:28.993Z</ctyp:Epoch>
                <ctyp:TypeOfEphemeris>SGP</ctyp:TypeOfEphemeris>
                <ctyp:Inclination uom="rad">2.976014</ctyp:Inclination>
                <ctyp:RightAscensionAscendingNode uom="rad">4.404757</ctyp:RightAscensionAscendingNode>
                <ctyp:Eccentricity>0.75241</ctyp:Eccentricity>
                <ctyp:ArgPerigee uom="rad">4.474624</ctyp:ArgPerigee>
                <ctyp:MeanAnomaly uom="rad">3.8055502</ctyp:MeanAnomaly>
                <ctyp:MeanMotion uom="rev/d">4.67905815</ctyp:MeanMotion>
                <ctyp:EpochRevolution>29</ctyp:EpochRevolution>
              </ctyp:OrbitalElements>
            </ntyp:OrbitalElementSet>
          </nsc:OrbitalElementSetCollection>
        </nsc:OrbitalElementSetMsg>
      </ssel:OrbitalElementSetMsgCollection>
    </ssel:ElementSetResponse>
  </soap:Body>
</soap:Envelope>
```


Fig. 8 Element Set Sample

4. NET-CENTRIC CONSIDERATIONS

Several data sources are required to achieve SSA. Currently these data sources lack common protocols, standards and formats. Some of these sources are the result of analysts' reports and these reports may be produced as a Word document, PowerPoint presentation, or wiki page. This variety in data formats introduces challenges when attempting to exchange the data for further processing by clients.

Transitioning from point-to-point communication to a net-centric paradigm requires the data be understood. Common terms may have different meanings to different people. A good example would be the term "Satellite". This could mean:

- all man-made objects performing a mission
- all man-made objects
- all objects orbiting a celestial body

Establishment of a Community of Interest (COI) plays a key role in implementing understandable net-centric data sharing. Understandable data focuses on reaching agreement on the meaning of information between the producers and consumers. This COI has Subject Matter Expert (SME) participation to arrive at a common vocabulary, lexicon, ontology, and eXtensible Markup language (XML) data schema. The artifacts that make up the data model form a common vocabulary to exchange information between major program components, as well as with external systems, applications and services. The data model consists of the following artifacts:

- Data Definitions (Logical Data Model)
- XML Schema (Physical Data Model)
- Service Description Documentations
- Web Service Description Language (WSDL)s
- Design & Implementation Guidance

To make the information visible to the community, many of these products are registered into the Data Services Environment (DSE). Thus, client application developers can gain access to the information necessary to understand and access exposed data items.

The *JSpOC Mission System (JMS) Common Data Model: Foundation for Net-Centric Interoperability for Space Situational Awareness* [3] defines the steps being taken to establish the SSA COI and develop the JMS Common Data Model.

Multiple data sources offer similar information. When these sources do not agree it is important for the client to understand the source. Providing the data pedigree with the mission data will enable the client to trust the data provided from a given source. Additionally, encryption of the data in transport ensures the information has not been altered and allows the clients to trust the data source's information.

The evolution of exposing SSA data net-centrically will increase the volume and velocity of data received by the SSA clients. The variety of the data will continue to be diverse in the future due to the need for unstructured reports generated by analysts. Increases in the number of SSA data sources exposed net-centrically will enable the ability to leverage the concepts of 'Big Data' and 'Cloud Computing'. These concepts are described in *Space Situational Awareness (SSA) Architecture Vision* [4].

Colonel Mike Wasson, Chief, Combat Operations Division, 614th Air and Space Operations Center, stated [5]:

"The JSpOC requires highly responsive SSA capabilities that rapidly detect, track, and characterize objects in space. As such, new developments in SSA tools and capability to assess and respond to events in space are imperatives for the future."

To accommodate this growth, an evolution of the Space Situational Awareness Architecture has been underway over the past several years. It has been moving away from a collection of stove piped systems with limited bandwidth, system specific message structures and aging equipment into a collection of systems that expose data net-centrically to establish a loosely coupled architecture that provides data from multiple sources to User Defined Operational Picture (UDOP) visualization clients and data processing clients. Further processing by the next generation of Net-centric message clients could be done providing:

- Current situational awareness
- Thread prediction
- Event attribution
- Anomaly resolution

5. CONCLUSION

Existing traditional and non-traditional data sources are evolving from stove piped connections to net-centric data exchanges.

Vast quantities of relevant SSA data exist today. Efforts have been underway for several years to make this data available Net-Centrically. This evolution from point-to-point communication to a net-centric communication model has the potential to increase the precision of the data exchanged and unlock additional data collected but not utilized by today's systems. This makes secondary data not currently transmitted available for SSA. Additionally, the new data structures allow the transmission of greater precision improving the quality of information exchanged.

Utilizing a common lexicon and agreed to data schemas will facilitate clients ability to understand and use the data. Thus, clients outside of the traditional set (Joint Space Operations Center) can quickly gain access and understand the available data enabling innovation of new usages for the existing data. Exposing available data sources net-centrically versus developing new sources will make necessary data available to clients faster.

As this data becomes available net-centrically, new and innovative client applications will provide greater mission utility. Over time this transition to a net-centric paradigm will support a large variety of space protection stake-holders with differing needs. Developers will need to continue to produce innovative client tools from this data. A governance process is necessary to evaluate these products and provide a path for incorporation into the operational JMS baseline.

The efforts to expose the data net-centrically need to continue. Additional data sources are needed to characterize and attribute space events. This will require continued work within the SSA COI to define the usable data structures.

Existing data sources contain untapped information. Net-centric data exposure techniques will make this data available versus developing new data sources. Non-technical, as well as technical challenges are being addressed to ensure this data will become available. The common lexicons and data models facilitate data understanding between disparate development teams. Thus, overall development costs are reduced.

6. REFERENCES

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