Optimized Autonomous Space In-situ Sensor Web for Volcano Monitoring

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Sponsors:

NASA

USGS
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OASIS End-Users

Nova: In the path of a killer volcano, 1993

OASIS End-Users (II)

Nova: In the path of a killer volcano, 1993

OASIS Background

- Volcano monitoring and crisis management
  - Within the US: USGS Volcano Observatories.
  - Worldwide: USGS - State Department, Volcano Disaster Assistance Program (VDAP)
- Volcano monitoring involves several disciplines
  - Geology
  - Gas Geochemistry
  - Petrology
  - Seismology
  - Remote sensing
- History
  - Disciplines have evolved along parallel trajectories (and networks).
  - Data Assimilation does not typically affect network operations decisions in real time.
- Where NASA can help:
  - Space measurements
  - Team with the end-user to develop an end-to-end "systems" approach to volcano hazards assessment and crisis management.

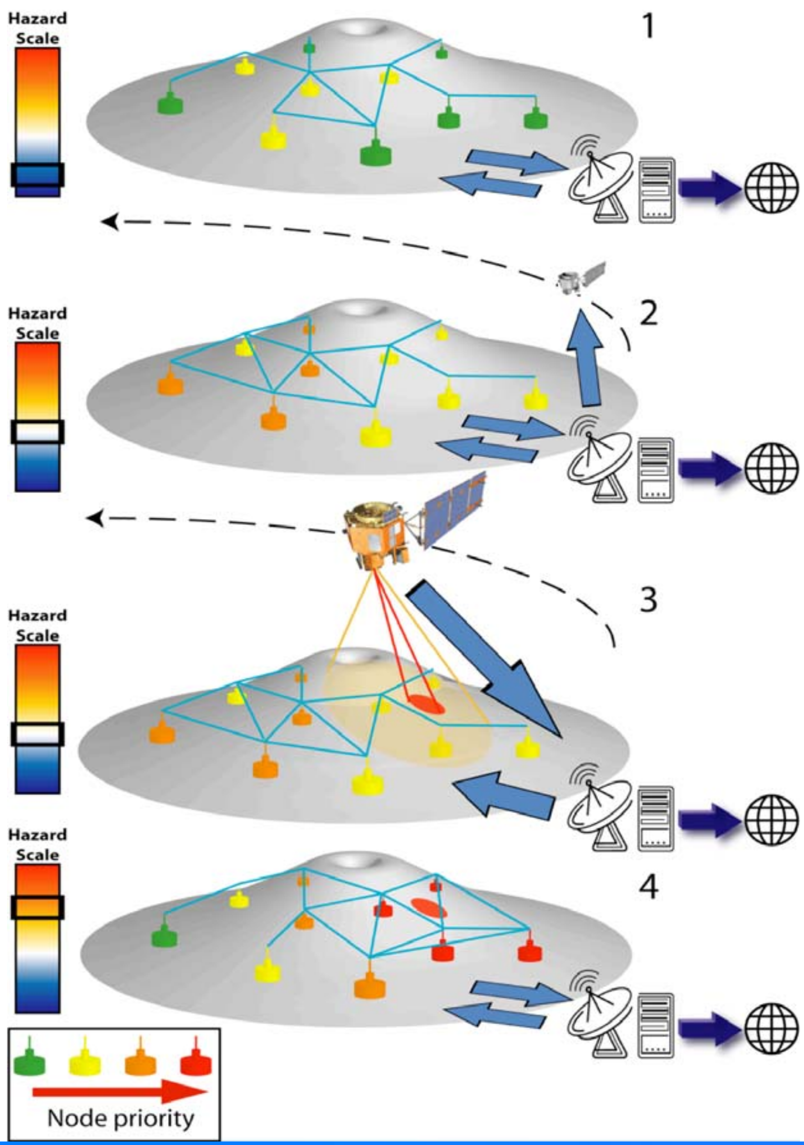
OASIS Objectives

- Develop a prototype real-time Optimized Autonomous Space - In-situ Sensor-web, with a focus on volcano hazard mitigation and with the goals of:
  - Integrating complementary space and in-situ elements into an interactive, autonomous sensor-web.
  - Advancing sensor-web power and communication resource management technology.
  - Enabling scalability and seamless infusion of future space and in-situ assets into the sensor-web.

OASIS System Requirements

- Multidisciplinary effort:
  - Scientist & Engineers
  - In-situ & Remote sensing
  - Volcanologists, Remote sensing, Seismologists, Geodecists, Petrologists, Gas Geochemists,
- Provides NASA and the USGS with “blueprint” for future autonomous volcano monitoring networks.
- System requirements document availble.

Operational Concept



OASIS will have two-way communication capability between ground and space assets, use both space and ground data for optimal allocation of limited power and bandwidth resources on the ground, and use smart management of competing demands for limited space assets.

1. In-situ sensor-web autonomously determines topology, node bandwidth and power allocation.

2. Activity level rises causing self-organization of in-situ network topology and a request for re-tasking of space assets.

3. High-resolution remote-sensing data is acquired and fed back to the control center.

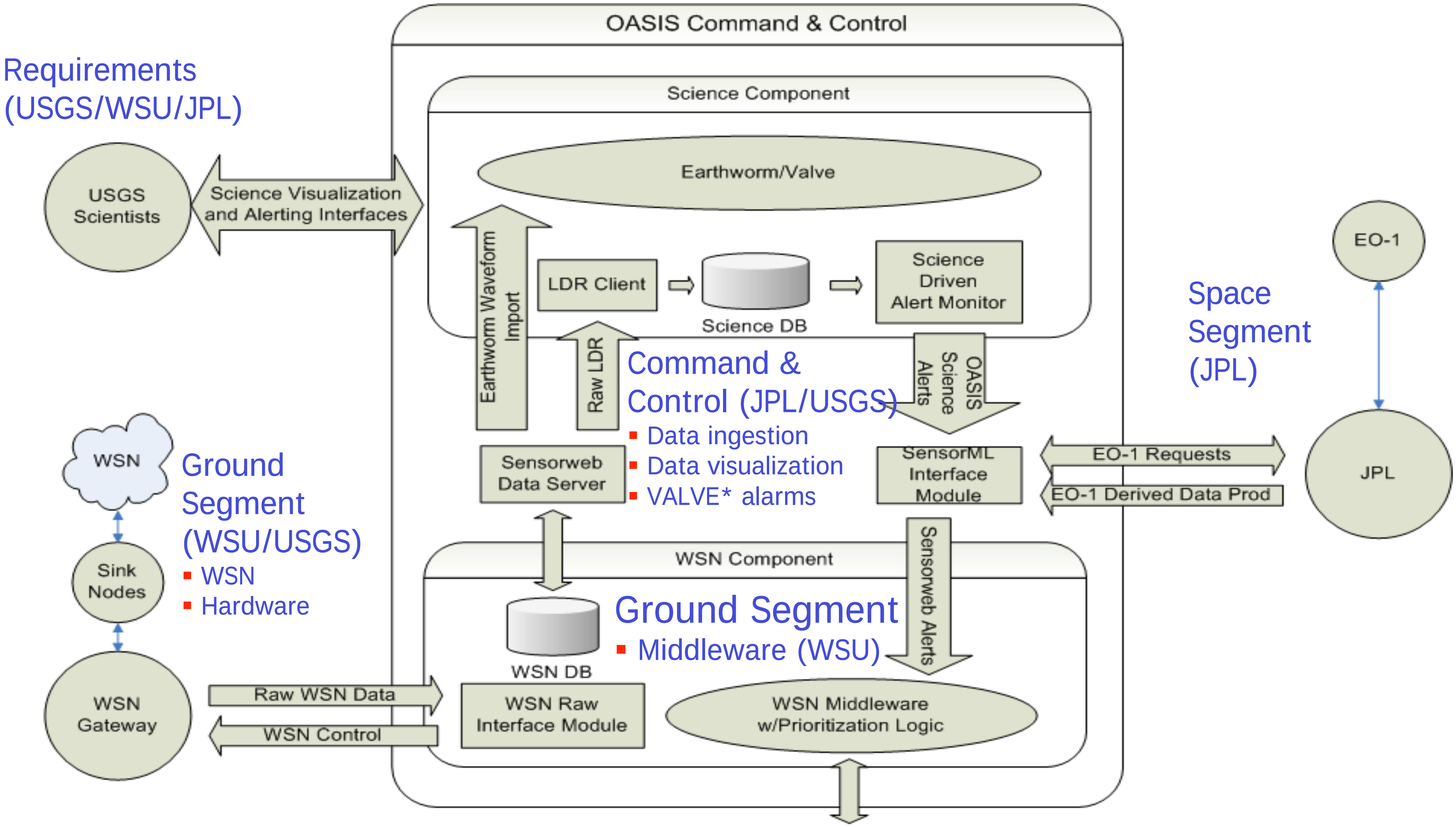
4. In-situ sensor-web ingests remote sensing data and re-organizes accordingly. Data are publicly available at all stages.

* Prototype: St, Helens 2009.

Design Principles

- The OASIS design will leverage existing software/processes wherever possible.
- The OASIS design will use commercial-off–the-shelf (COTS) components whenever possible.
- The OASIS design will strive to be generic enough to be used with ground and space assets other than those slated in the prototype.

OASIS System Architecture



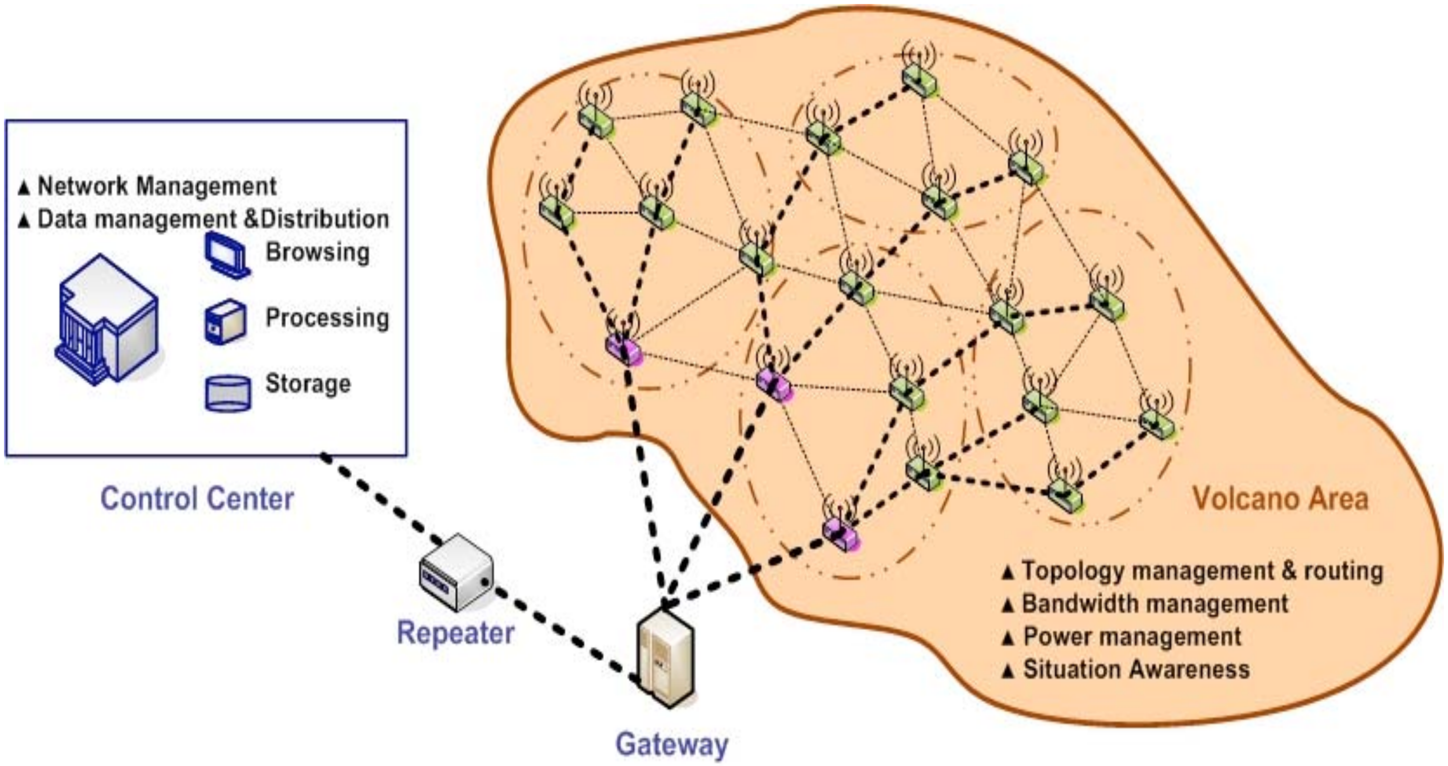
WSN - Wireless Sensor Network
LDR - Low Data Rate (i.e. non-waveform data)

* Volcano Analysis and Visualization Environment

OASIS Space segment (EO-1)

- **Part of the New Millennium Program**
- **Management and Operations**: Goddard Space Flight Center (GSFC)
- **Launch:** November 21, 2000
- **Orbit**: Low-Earth
- **Instruments**: Advanced Land Imager (ALI) and Hyperion Hyperspectral Imager (HSI)

OASIS Ground Segment



In-Situ Sensor Web architecture

1. Sensor-nodes form logical clusters for network management and situation awareness; data flow forms a dynamic data diffusion tree rooted at gateway.
2. Smart bandwidth and power management according to environmental changes and mission needs.
3. Remote control center manages network and data, and interacts with space assets and Internet.

AIST OASIS Development

- In-situ sensor-web
  - Hardware design and assembly (USGS)
  - Node software (WSU Vancouver)
  - Node Middleware (WSU Pullman)
  - Alerts and link to space component (JPL)
- Space and ground services for tasking, acquiring and ingesting data in real time (Space component is just another sensor)
  - Make science-based decisions in near real time.
  - Make efficient use of resources by translating scientific and engineering data into network operation decisions.
- A unified Command & Control software and GUI development (JPL)

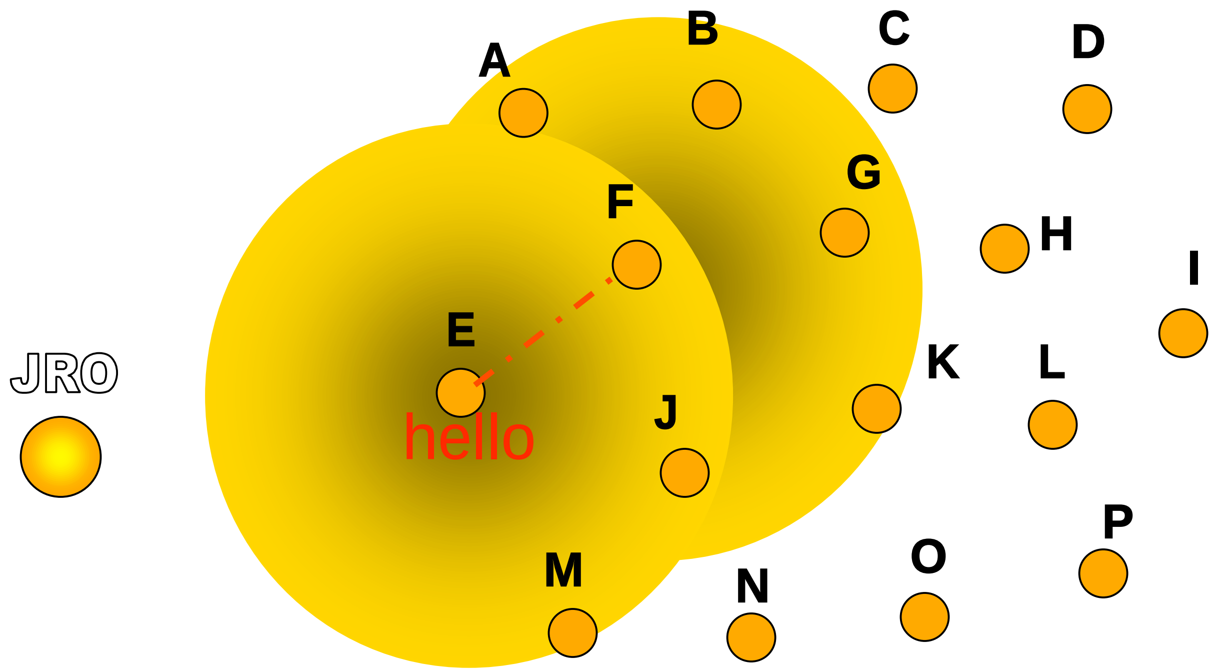
OASIS ground segment challenges

- Multiple sensors at each node
  - Different data rates requirement
  - Different priorities for different sensors at different times
- High data rates (100Hz seismic and infrasonic).
- Reliable two-way interaction of command and control module with sensor-web nodes.
- Operation in a hazardous, harsh, and ever changing environment (Volcanic gases, ash, snow & ice, rock falls).

Hardware prototype (USGS)

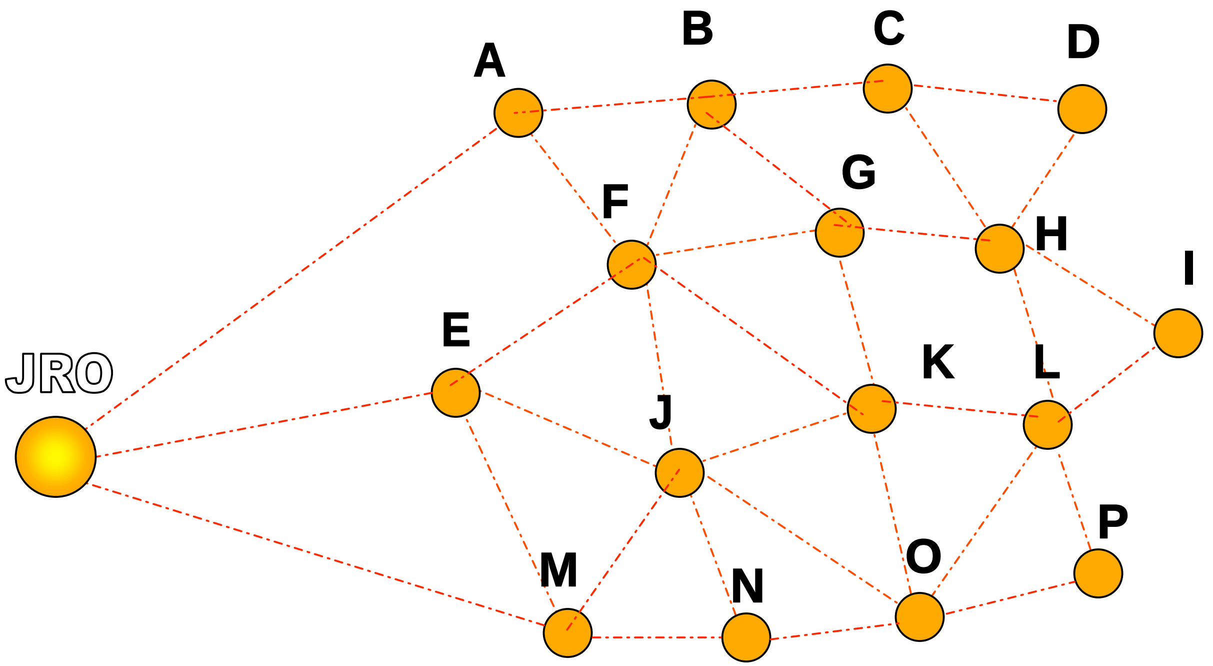
- Sensor suite
  - Seismic
  - GPS (deformation and timing)
  - Infrasound (explosions)
  - Lightning detection (ash)
- Sensor logic (imote 2)
- Communication
- Power (Requirement: 1 year)

Topology Management and Routing



neighbor discovery

Topology Management and Routing



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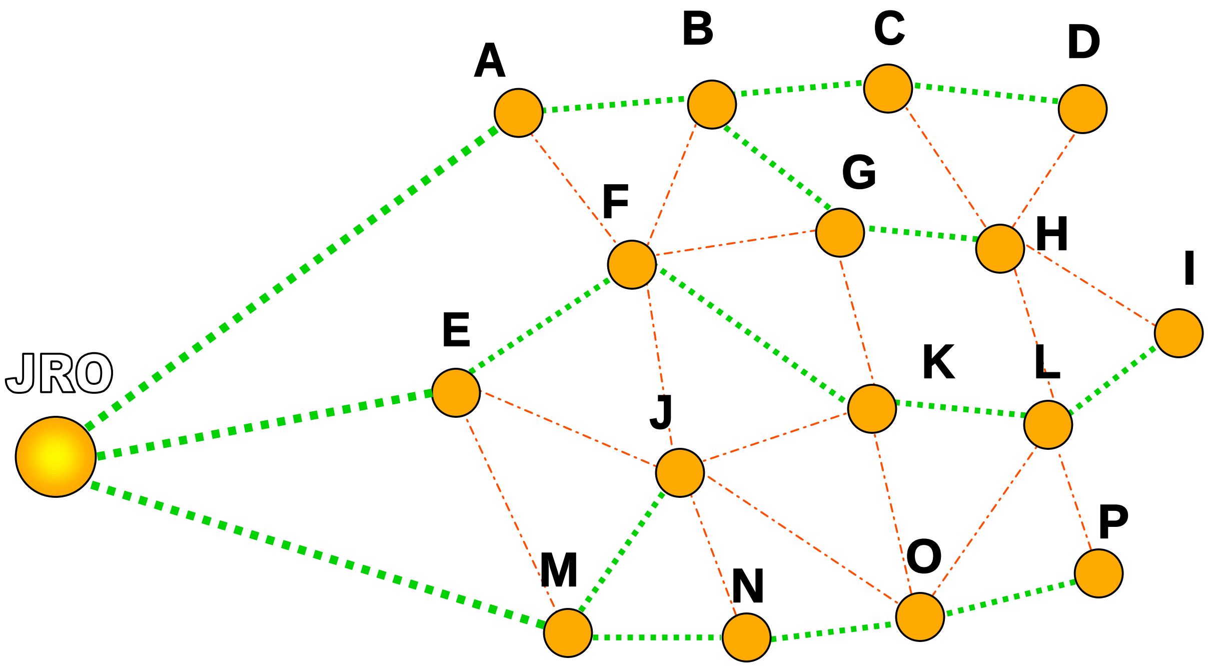
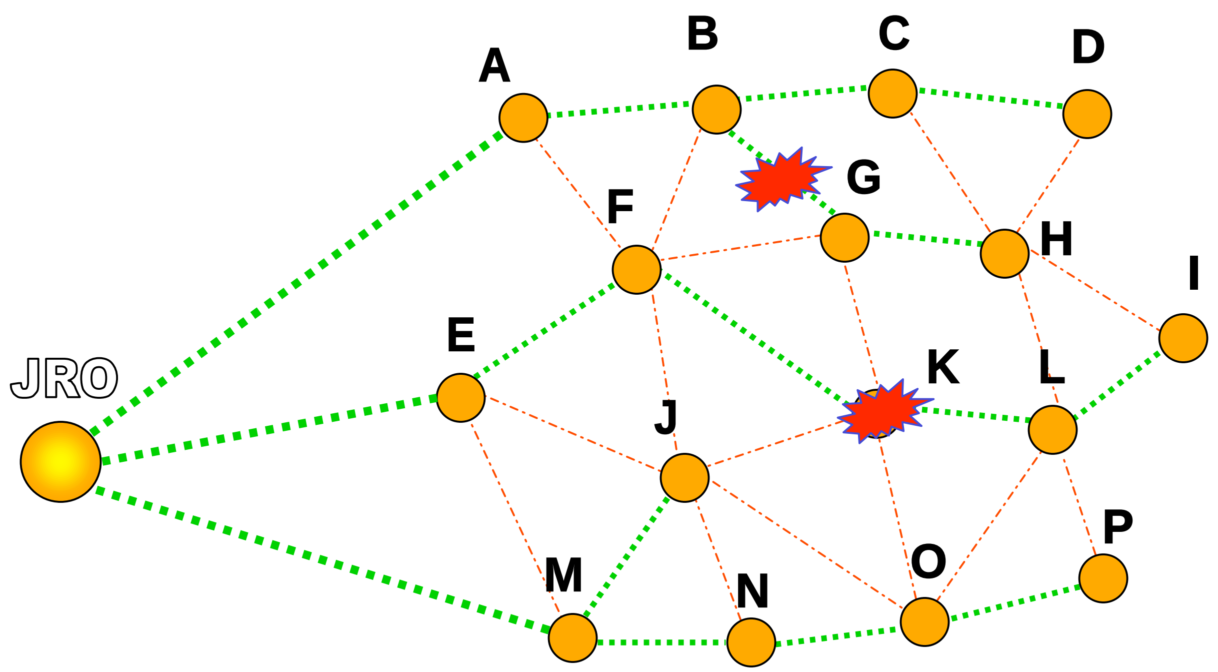
Topology Management and Routing



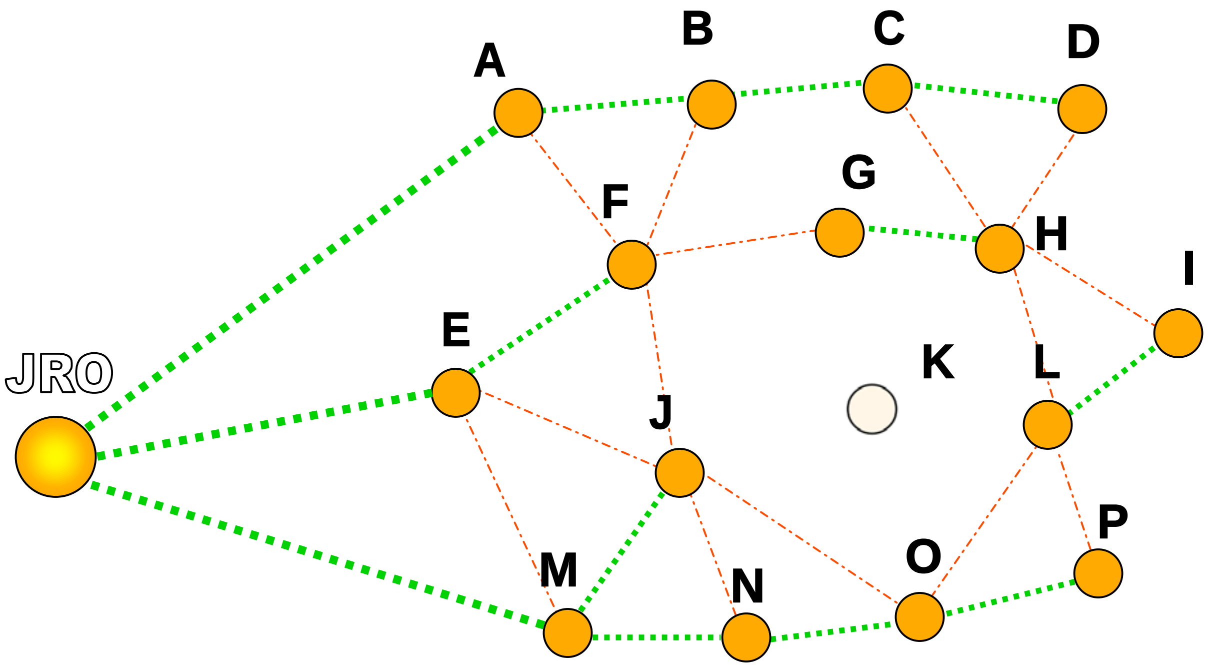
route discovery

Topology Management and Routing



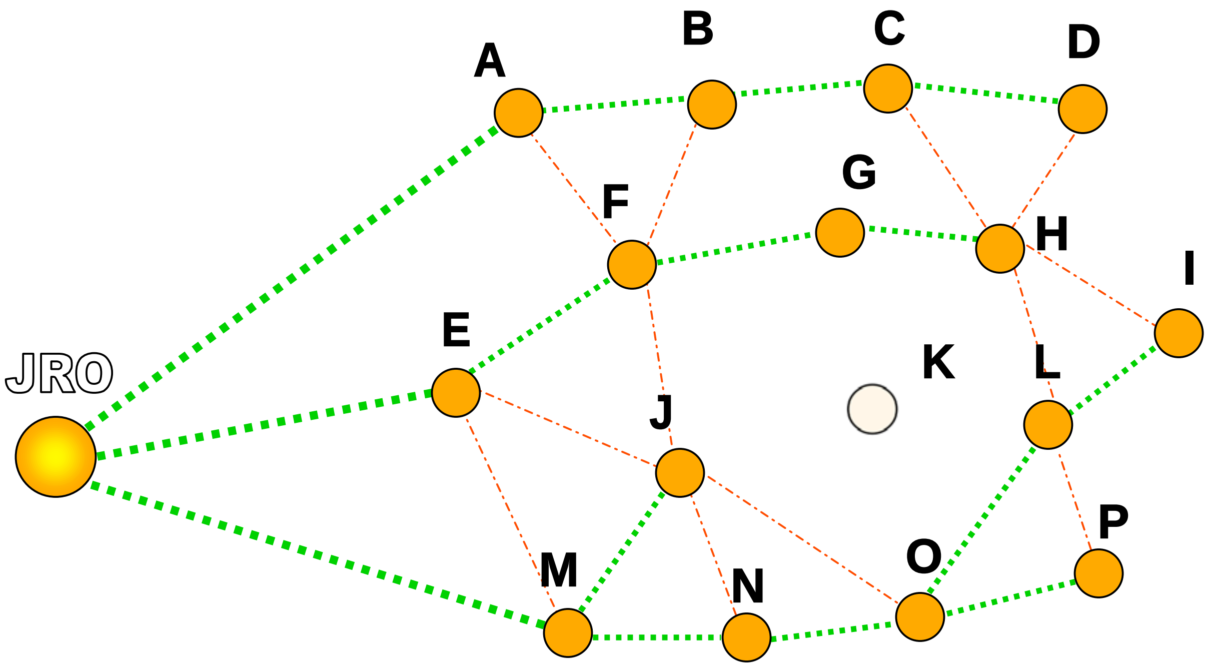
Self-healing and self-maintenance

Topology Management and Routing



Self-healing and self-maintenance

Topology Management and Routing



Self-healing and self-maintenance

Situation Awareness - Node

- Resource awareness
  - Adjust route to optimize resource usages (e.g., power, bandwidth).
  - Reserve bandwidth for high-priority data.
  - Adaptive loss-tolerable compression
- Environment awareness
  - Changes of volcanic activity will cause sensors to change behavior autonomously.
  - Act according to the input from space assets.

Situation awareness - Network

- Situation: network situation, environment situation and mission needs.
  - Network situation includes the network bandwidth, node buffer, computing power and battery energy situations.
  - Environment situation includes the current environment status (e.g. volcano eruption or quiet).
  - The mission needs come from the feedback of space asset, user input and scienc agent.
- Priority of sensor types. For instance, during eruption, gas sensor reading is more useful than seismic reading; on the other hand, during quiescence, seismic reading is more important.
- Priority of node locations. If we can not get data from all sensors, we shall be able to automatically identify the minimum set of sensors that will provide mission critical data.

V-Alarms

- Provides a mechanism to identify events in data series and perform actions as a result of those events.
- Data are stored in an MySQL database
- ‘Triggers’ identify events using SQL queries as time progresses
- Triggers returning positive result in:
  - a data summarization
    - further SQL queries, and static data labels
    - Wrapped in XML
  - A series of actions transmitting data summarization:
    - Data summarization format can be transformed using XSLT
    - Protocols: HTTP Post, TCP/IP Socket, SMTP (email), ...
    - Can be used to communicate to web-services, i.e. to EO-1 or OASIS ground-control

Data Management

- Port to USGS existing tools (e.g., EARTHWORM, VALVE, SWARM)
  - database for real-time data storage
  - web tools for seismic, GPS data visualization
- OGC SWE for Ground <-> Space Linkage and future inter-geo-system data sharing
  - Web Services are part of the Open Geospatial Consortium (OGC) evolving standards for Sensor Web Enablement (SWE).

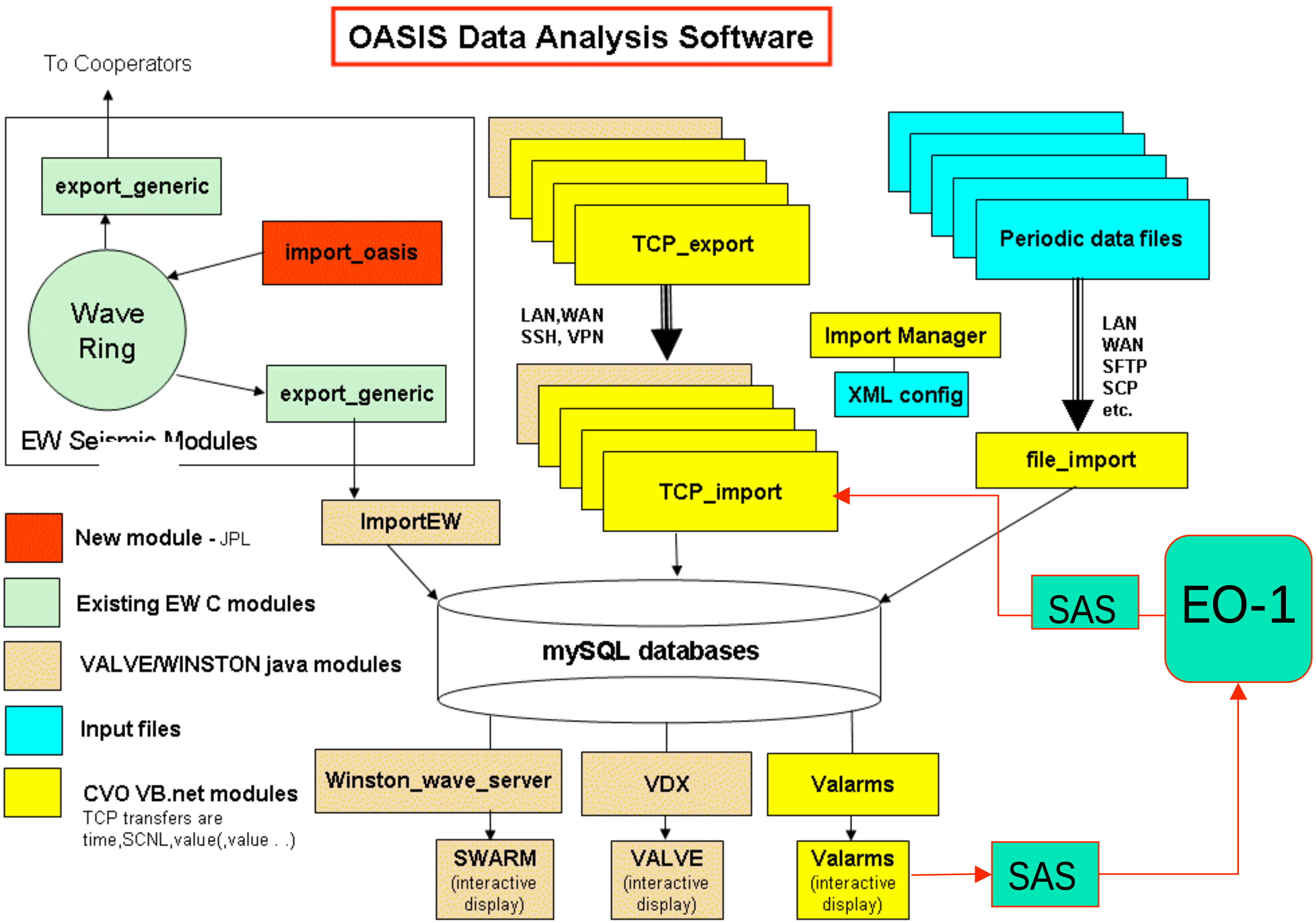
Ground<->Space Interfacing

- Designing OGC SWE services for OASIS network sensors
  - To task to acquire new data
  - Acquire archived data
  - Subscribe to alerts
  - Process data
- Space -> Ground feedback of request status and data under development
- Autonomous ingestion of space data for hazard assessment and ground network operation decisions.

OGC Web Services for ground and space segments

- Sensor Planning Service (SPS)
  - Used to determine if a sensor is available to acquire requested data and for tasking a sensor
- Sensor Observation Service (SOS)
  - Used to retrieve engineering or science data including data acquired from the SPS
- Sensor Alert Service (SAS)
  - Used to publish and subscribe to sensor alerts. Client can register a specific criteria for alerts.
- Web Processing Service (WPS)
  - Used to perform a calculation on the acquired sensing data, including processing the raw data into derivatives such as vegetation indices, lava flows, flood coverage, etc...

OASIS Data flow



Deployment and Test Plan

- Link Space and ground in progress
- Integration of OASIS with USGS tools in progress
- In-situ deployment:
  - 5 nodes trial deployment for evaluation in summer 2008
  - 15 nodes final deployment to Mount St. Helens in summer 2009

Future development

- Smart(er) data analysis for:
  - Hazard assessment.
  - Network operation decisions.
- UAVSAR
  - Use OASIS to assess need for UAVSAR deployment.
  - Use OASIS to plan flight line to maximize data return.
  - Combine OASIS and UAVSAR data to provide end-user (VDAP) with a physical assessment of the volcano crisis evolution.

Acknowledgement

- NASA ESTO AIST and USGS Volcano Hazard Program
- A multidisciplinary team involves:
  - Washington State University
    - WenZhan Song (Assistant Professor, WSU)
    - Behrooz Shirazi (Chair Professor, EECS director, WSU)
    - WSU Students: Ray Wang, Yang Peng, Nina Picone, Fenghua Yuan, Tony Mancill, Renjie Huang, Andy Ma, Rashmi Parthasarathy, Lohith A Rangappa
  - Jet Propulsion Laboratory
    - Steve Chien (Principal Computer Scientist, JPL)
    - Sharon Kedar (Geophysicist, JPL)
    - Frank Webb (Principal Manager, JPL)
    - Ashley Davies (Geophysicist, JPL)
    - Daniel Tran (Software Engineer, JPL)
    - Joshua Doubleday (Software Engineer, JPL)
    - David Pieri (Volcanologist, JPL)
    - Caroline Racho (system Engineer, JPL)
  - USGS Cascade Volcano Observatory
    - Rick LaHusen (Senior Instrumentation Engineer, CVO)
    - Cynthia Gardener (Science-in-charge, CVO)
    - John Pallister (Geologist, CVO)
    - Dan Dzurisin (Geophysicist, CVO)
    - Seth Moran (Seismologist , CVO)
    - Mike Lisowski (Geophysicist , CVO)
    - Greg Speers (Electronic Engineer, CVO)
    - Kelly Swinford (Electronic Technician, CVO)
  - Goddard Space Flight Center
    - Dan Mandl (EO-1 Mission Manager, GSFC)
    - Stuart Frye (EO-1 Systems Engineer, SGT)

For more information, visit

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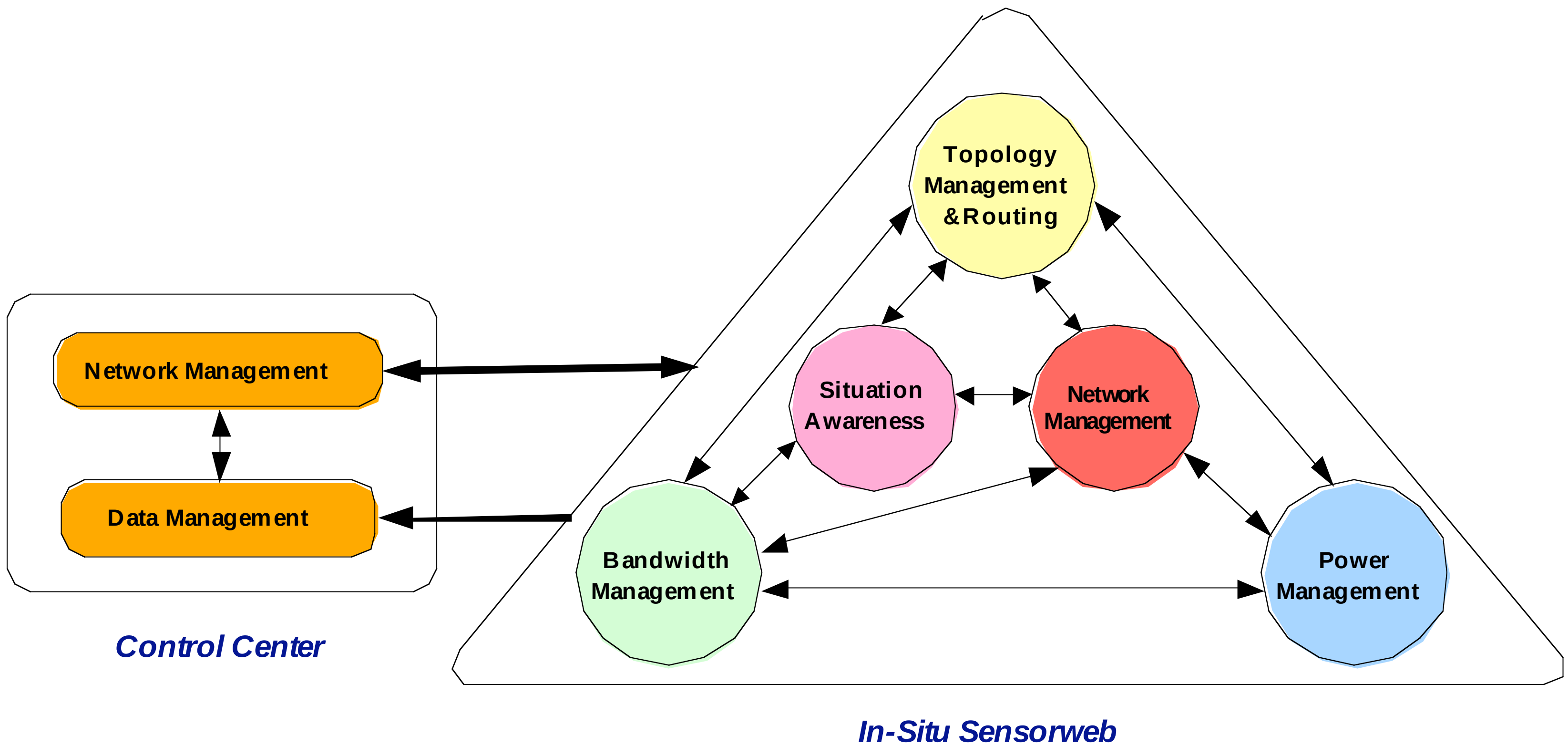
Backup slides

In-situ Infrastructure

In-situ Components



In-Situ Sensor Web Components Relationship

1. Topology Management & Routing, Bandwidth Management and Power Management runs autonomously to meet mission needs and optimize the resource usage.
2. Network Management module enable network status monitoring and external command & control from Space element, users or scientific agent softwares.
3. Data Management enables data sharing between in-situ sensorweb and other systems such as space element, USGS existing tools and Internet.

Compressive Network Sensing

- Adaptive data compression. Z data blocks are losslessly compressed to N compressed blocks (e.g., highest coefficients to lowest coefficients in wavelet, corresponding to highest priority to lowest priority blocks). Even if we got M<N blocks in a gateway, we can still recover the major original signals.
- Collaborative network compression
  - Make use of data correlations among neighbors to reduce redundant data.
  - Event detector to prioritize data blocks. In communication stacks, we may give higher priority and more retries to those higher priority packets.

Network Management

- Monitor the network status
  - Network topology
  - Node battery status
  - Packet delivery ratio
  - Data sampling rate of each node
- Command & Control
  - Inject feedback from space asset, user, and scientific agent software
  - Network adjust resource allocation accordingly
- Remote reprogramming
  - Upgrade software without risky and expensive field retrieval.

Prioritization: Tiny DWFQ

- Problem
  - High data collection rates
  - Different data types & priorities
  - Reduce loss of critical data
- Solution
  - Network Quality of Service scheduling algorithm
  - Tiny-Dynamic Weighted Fair Queuing (Tiny-DWFQ)*
    - Responds to automated feedback
      - Current congestion
      - Priorities
    - Dynamically reconfigures
    - Lightweight algorithm
    - Maximize available bandwidth and storage resources
    - Ensures high level Quality of Service (QoS) for high priority data
    - Maintains standard QoS for lower priority data

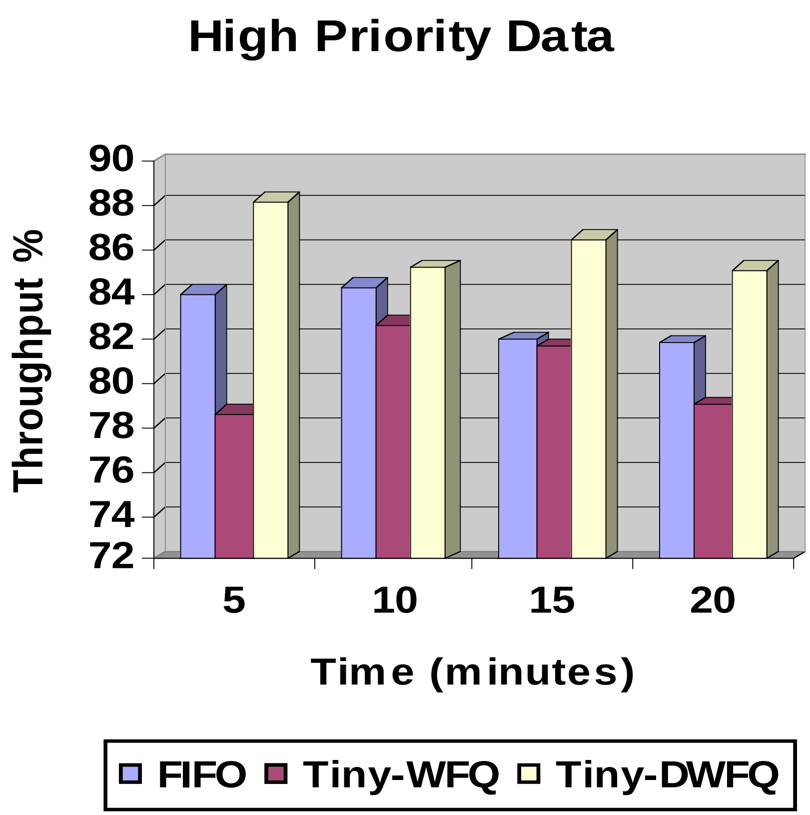
Prioritization algorithm test

- 10 Imote2 sensors
- Laboratory
- Reduced radio range
- Multihop traffic
  - Sent to sink node
  - Forwarded to laptop
- Topology
  - Random/scattered

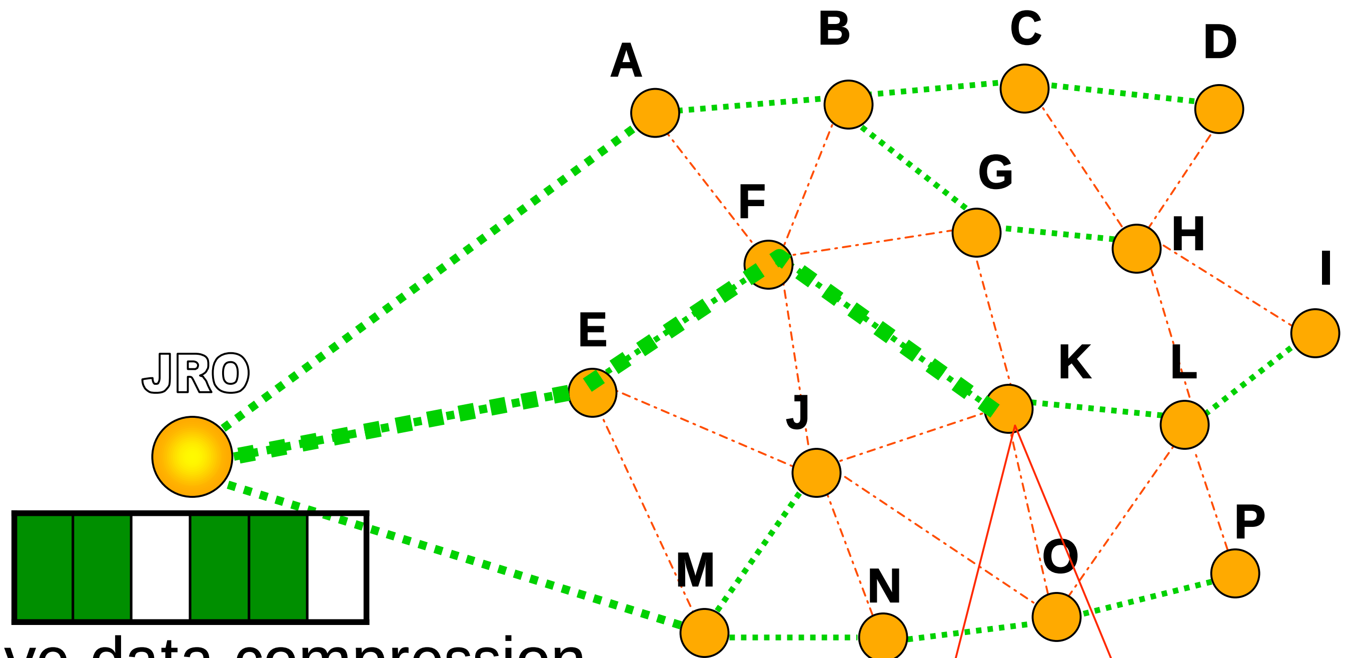
Data Type	**Sampling Rate (bytes/sec)**	**Priority**
Seismic RSAM	4	7
Seismic Event	0-200	5
Seismic Inter-Event	100	2
Infrasonic RSAM	4	6
Infrasonic Event	0-200	4
Infrasonic Inter-Event	100	1
Lightning	2	6

Prioritization algorithm test results

- Compared Tiny-DWFQ to:
  - Tiny-WFQ
  - FIFO
- Throughput
  - Tiny-DWFQ increased throughput percentage
    - For all data types
- Packet Loss
  - Tiny-DWFQ decreased packet loss
    - For all types of data.



Adaptive Data Compression



Adaptive data compression mechanism

- adjust compression ratio based on bandwidth availability.
- no packet inter-dependency.