OGC® Sensor Web Enablement: Overview and High Level Architecture

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Abstract. The Open Geospatial Consortium (OGC) standards activities that focus on sensors and sensor networks comprise an OGC focus area known as Sensor Web Enablement (SWE). Readers interested in greater technical and architecture details can download the OGC SWE Architecture Discussion Paper titled "The OGC Sensor Web Enablement Architecture" (OGC document 06-021r1).

Keywords: Open Geospatial Consortium, Inc., OGC, sensors, sensor webs, standards, Sensor Web Enablement (SWE), Observations & Measurements Schema (O&M), Sensor Model Language (SensorML, Transducer Model Language (TransducerML or TML), Sensor Observations Service (SOS), Sensor Planning Service (SPS), Sensor Alert Service (SAS), Web Notification Services (WNS).

1 Introduction

Sensor Web Enablement (SWE) in the Open Geospatial Consortium, Inc. (OGC)[1] context refers to web accessible sensor networks and archived sensor data that can be discovered, accessed and, where applicable, controlled using open standard protocols and interfaces (APIs). Sensor location is usually a critical parameter for sensors on the Web, and the OGC sets geospatial industry standards, so SWE standards are being harmonized with other OGC standards for geospatial processing.

Members of the OGC are building a framework of open standards for exploiting Web-connected sensors and sensor systems of all types: flood gauges, air pollution monitors, stress gauges on bridges, mobile heart monitors, Webcams, satellite-borne earth imaging devices and countless other sensors and sensor systems.

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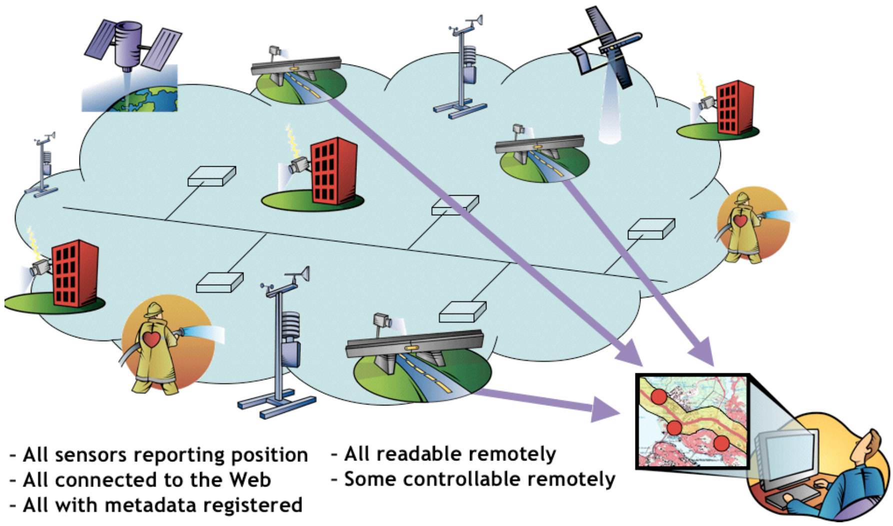
[1] The OGC is an international consortium of industry, academic and government organizations who collaboratively develop open standards for geospatial and location services. (See http://www.opengeospatial.org.)

S. Nittel, A. Labrinidis, and A. Stefanidis (Eds.): GSN 2006, LNCS 4540, pp. 175–190, 2008.



(Image courtesy of the OGC)

Fig. 1. Sensor Web Concept

SWE has extraordinary potential significance in many domains of activity, as the costs of sensor and network components fall, as their combined use spreads, and as the underlying Web services infrastructure becomes increasingly capable. The OGC consensus standards process coupled with strong international industry and government support in domains that depend on sensors has resulted in SWE standards that are quickly becoming established in all application areas where such standards are of use.

2 Overview

In much the same way that Hyper Text Markup Language (HTML) and Hypertext Transfer Protocol (HTTP) standards enable the exchange of almost any type of information on the Web, the OGC's SWE standards enable the Web-based discovery, exchange, and processing of sensor observations, as well as the tasking of sensor systems. The functionality includes:

- Discovery of sensor systems, observations, and observation processes that meet an application or users immediate needs;
- Determination of a sensor's capabilities and quality of measurements;
- Access to sensor parameters that automatically allow software to process and geo-locate observations;
- Retrieval of real-time or time-series observations and coverages in standard encodings

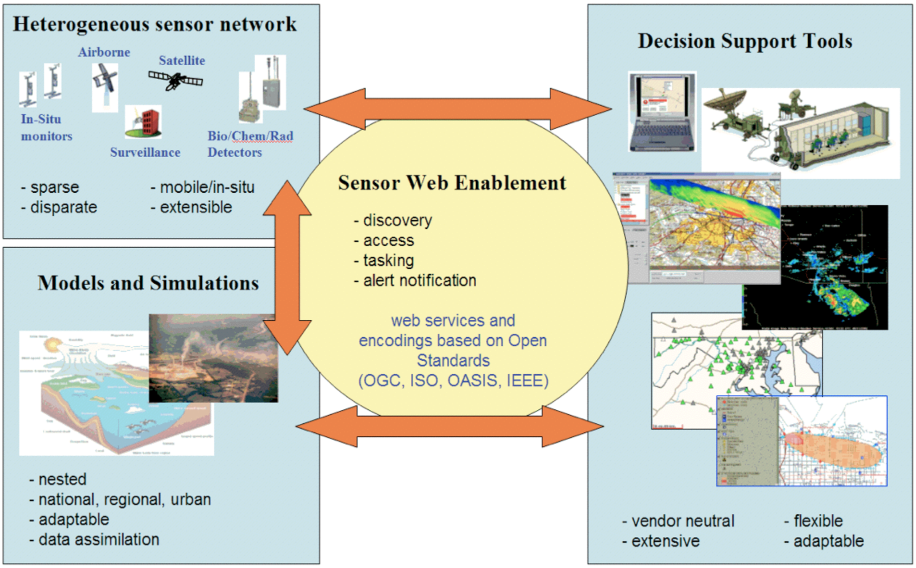
- Tasking of sensors to acquire observations of interest;
- Subscription to and publishing of alerts to be issued by sensors or sensor services based upon certain criteria.

Below is a list of the OpenGIS® Standards that make up the SWE suite of standards. Each specifies encodings for describing sensors and sensor observations and/or interface definitions for web services:

1. **Observations & Measurements Schema (O&M)** – (OGC Adopted Standard) Standard models and XML Schema for encoding observations and measurements from a sensor, both archived and real-time.
2. **Sensor Model Language (SensorML)** – (OGC Adopted Standard) Standard models and XML Schema for describing sensors systems and processes; provides information needed for discovery of sensors, location of sensor observations, processing of low-level sensor observations, and listing of taskable properties.
3. **Transducer Markup Language (TransducerML or TML)** – (OGC Adopted Standard) The conceptual model and XML Schema for describing transducers and supporting real-time streaming of data to and from sensor systems.
4. **Sensor Observations Service (SOS)** – (OGC Adopted Standard) Standard web service interface for requesting, filtering, and retrieving observations and sensor system information. This is the intermediary between a client and an observation repository or near real-time sensor channel.
5. **Sensor Planning Service (SPS)** – (OGC Adopted Standard) Standard web service interface for requesting user-driven acquisitions and observations. This is the intermediary between a client and a sensor collection management environment.
6. **Sensor Alert Service (SAS)** – (OGC Best Practices document) Standard web service interface for publishing and subscribing to alerts from sensors.
7. **Web Notification Services (WNS)** – (OGC Best Practices document) Standard web service interface for asynchronous delivery of messages or alerts from SAS and SPS web services and other elements of service workflows.

XML is a key part of the infrastructure that supports SWE. When the network connection for a sensor or system is layered with Internet and Web protocols, eXtensible Markup Language (XML) schemas defined in SWE standards can be used to publish formal descriptions of the sensor's capabilities, location, and interfaces. Then Web brokers, clients and servers can parse and interpret the XML data, enabling automated Web-based discovery of the existence of sensors and evaluation of their characteristics based on their published descriptions. The information provided also enables applications to geolocate and process sensor data without requiring *a priori* knowledge of the sensor system.

Information in the XML schema about a sensor's control interface enables automated communication with the sensor system for various purposes: to determine, for example, its state and location; to issue commands to the sensor or its platform; and, to access its stored or real-time data. This approach to sensor and data description also



(Image courtesy of the OGC)

Fig. 2. The role of the Sensor Web Enablement framework

provides an efficient way to generate comprehensive standard-schema metadata for data produced by sensors, facilitating the discovery and interpretation of data in distributed archives.

3 The SWE Standards Framework

Below we describe each of the seven SWE standards.

3.1 Observations and Measurements (O&M)

The OpenGIS Observations and Measurements (O&M) Standard provides a standard model for representing and exchanging observation results. O&M provides standard constructs for accessing and exchanging observations, alleviating the need to support a wide range of sensor-specific and community-specific data formats. O&M combines the flexibility and extensibility provided by XML with an efficient means to package large amounts of data as ASCII or binary blocks.

The Observations and Measurements (O&M) Standard describes a conceptual model and XML encoding for measurements and observations. O&M establishes a high-level framework for representing observations, measurements, procedures and metadata of sensor systems and is required by the Sensor Observation Service Standard, for implementation of SWE-enabled architectures, and for general support for OGC standards compliant systems dealing in technical measurements in science and engineering.

3.2 Sensor Model Language (SensorML) [2]

The OpenGIS Sensor Model Language (SensorML) Standard provides an information model and encodings that enable discovery and tasking of Web-resident sensors and exploitation of sensor observations.[i]

The measurement of phenomena that results in an observation consists of a series of *processes* (also called *procedures*), beginning with the processes of sampling and detecting and followed perhaps by processes of data manipulation.

SensorML defines models and XML Schema for describing any process, including measurement by a sensor system, as well as post-measurement processing.

Within SensorML, everything including detectors, actuators, filters, and operators is defined as a process model. A *Process Model* defines the *inputs*, *outputs*, *parameters*, and *method* for that process, as well as a collection of metadata useful for discovery and human assistance. Because SensorML provides a functional model of the sensor system, rather than a detailed description of its hardware, each component can be included as part of one or more process chains that can either describe the lineage of the observations or provide a process for geolocating and processing the observations to higher level information.

3.3 TransducerML (TML)

The OpenGIS® Transducer Markup Language (TML) Encoding Standard is an efficient application and presentation layer communication protocol for exchanging live streaming or archived data to (i.e. control data) and/or sensor data from any sensor system. A sensor system can be one or more sensors, receivers, actuators, transmitters, and processes. A TML client can be capable of handling any TML enabled sensor system without prior knowledge of that system.

The protocol contains descriptions of both the sensor data and the sensor system itself. It is scalable, consistent, unambiguous, and usable with any sensor system incorporating any number sensors and actuators. It supports the precise spatial and temporal alignment of each data element. It also supports the registration, discovery and understanding of sensor systems and data, enabling users to ignore irrelevant data. It can adapt to highly dynamic and distributed environments in distributed net-centric operations.

The sensor system descriptions use common models and metadata and they describe the physical and semantic relationships of components, thus enabling sensor fusion.

TML was introduced into the OGC standards process in 2004 and is now part of the SWE family of standards. It complements and has been harmonized with SensorML and O&M. TML provides an encoding and a conceptual model for streaming real-time “clusters” of time-tagged and sensor-referenced observations from a sensor system. SensorML describes the system models that allow a client to interpret, geolocate, and process the streaming observations.

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[2] SensorML got its start in earlier NASA and CEOS (Committee for Earth Observation Satellites) projects. It was brought into OGC because OGC provides a process in which this and other elements of Sensor Web Enablement could be developed in an open consensus process.

3.4 Sensor Observation Service (SOS)

The OpenGIS Sensor Observation Service Interface Standard defines an API for managing deployed sensors and retrieving sensor observation data. SOS provides access to observations from sensors and sensor systems in a standard way that is consistent for all sensor systems including remote, in-situ (e.g., water monitoring), fixed and mobile sensors (including airborne / satellite imaging). The SOS is a critical element of the SWE architecture, defining the network-centric data representations and operations for accessing and integrating observation data from sensor systems.

The SOS mediates between a client and an observation repository or near real-time sensor channel. Clients can also access SOS to obtain metadata information that describes the associated sensors, platforms, procedures and other metadata associated with observations.

Registries (also called catalogs) play an important role. The schema for each sensor platform type is available in a registry, and sensors of that type are also in registries, with all their particular information. The schema for each observable type is available in a registry, and stored collections (data sets) of such observables and live data streams of that type are also in registries. Searches on the registries might reveal, for example, all the active air pollution sensors in London. Similarly, automated methods implementing the SOS standard might be employed in an application that displays a near real-time air pollution map of the city.

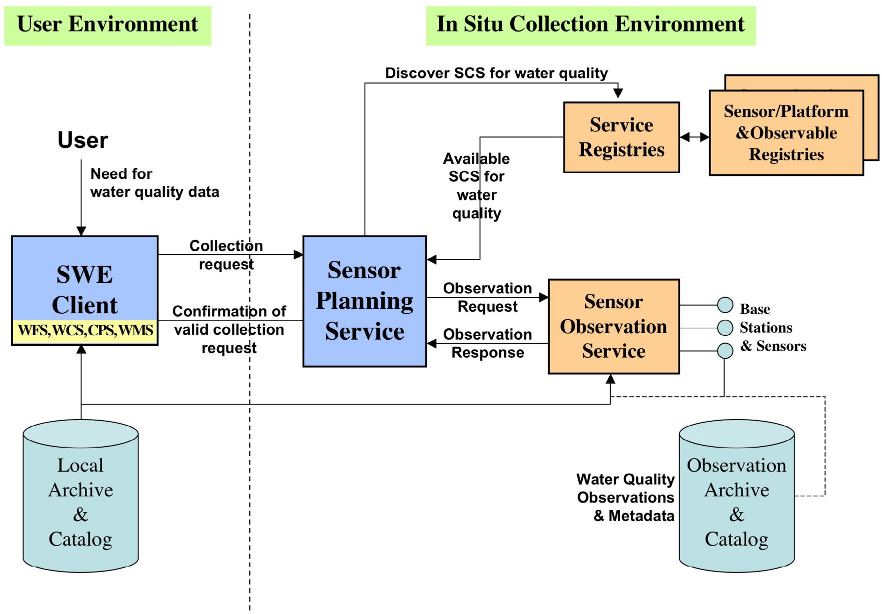
3.5 Sensor Planning Service (SPS)

The OpenGIS® Sensor Planning Service (SPS) Interface Standard defines interfaces for queries that provide information about the capabilities of a sensor and how to task the sensor. The standard is designed to support queries that have the following purposes: to determine the feasibility of a sensor planning request; to submit such a request; to inquire about the status of such a request; to update or cancel such a request; and to request information about other OGC Web services that provide access to the data collected by the requested task.

An example of an environmental support system is diagrammed above in Figure 3. This system uses SPS to assist scientists and regulators in formulating collection requests targeted at water quality monitoring devices and data archives. Among other things, it allows an investigator to delineate geographic regions and time frames, and to choose quality parameters to be excluded or included.

3.6 Sensor Alert Service (SAS)

The OpenGIS® Sensor Alert Service Best Practices Paper (OGC Document 06-028r3) specifies interfaces for requesting information describing the capabilities of a Sensor Alert Service, for determining the nature of offered alerts, the protocols used, and the options to subscribe to specific alert types. The document defines an alert as a special kind of notification indicating that an event has occurred at an object of interest, which results in a condition of heightened watchfulness or preparation for action. Alerts messages always contain a time and location value. The SAS acts like a registry rather than an event notification system. That is, the SAS will not send any alerts. All actual messaging is performed by a messaging server.



(Image courtesy of the OGC)

Fig. 3. Typical in situ Sensor Planning Service

3.7 Web Notification Service (WNS)

The OpenGIS® Web Notification Service (WNS) Best Practices Paper (OGC Document 06-095) specifies an open interface for a service by which a client may conduct asynchronous dialogues (message interchanges) with one or more other services. As services become more complex, basic request-response mechanisms need to contend with delays and failures. For example, mid-term or long-term transactions demand functions to support asynchronous communications between a user and the corresponding service, or between two services, respectively. A WNS is required to fulfill these needs within the SWE framework.

4 Sensor Web Standards Harmonization

4.1 IEEE 1451 Transducer Interfaces

An open standards framework for interoperable sensor networks needs to provide a universal way of connecting two basic interface types – transducer interfaces and application interfaces. Specifications for transducer interfaces typically mirror hardware specifications, while specifications for service interfaces mirror application requirements. The sensor interfaces and application services may need to interoperate and may need to be bridged at any of many locations in the deployment hierarchy.

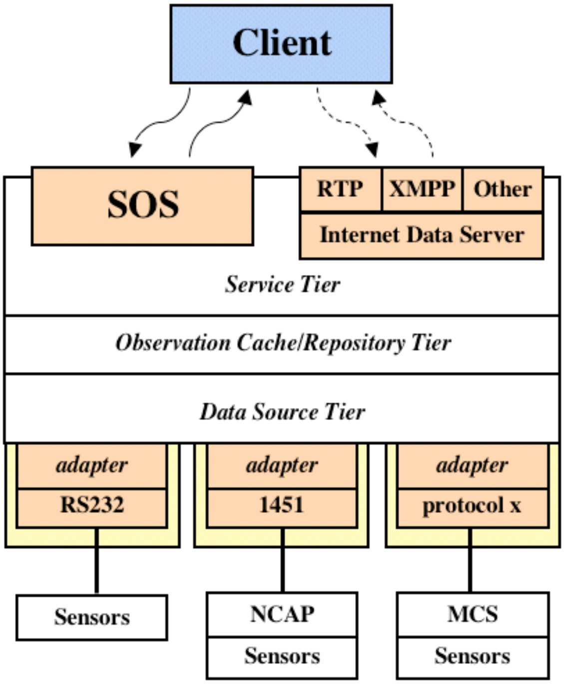


Fig. 4. IEEE-1451 in the SWE Interoperability Stack (Image courtesy of the OGC)

At the transducer interface level, a "smart" transducer includes enough descriptive information so that control software can automatically determine the transducer's operating parameters, decode the (electronic) data sheet, and issue commands to read or actuate the transducer.

To avoid the requirement to make unique smart transducers for each network on the market, transducer manufacturers have supported the development of a universally accepted transducer interface standard, the IEEE 1451 standard.

The object-based scheme used in 1451.1 makes sensors accessible to clients over a network through a Network Capable Application Processor (NCAP), and this is the point of interface to services defined in the OGC Sensor Web Enablement standards. In Figure 4, SWE services such as SOS act as clients (consumers) of IEEE-1451 NCAP services and TEDS documents, thereby enabling interactions with heterogeneous sensor systems via scalable networks of applications and services.

In addition to IEEE 1451, the SWE standards foundation also references other relevant sensor and alerting standards such as the OASIS Common Alerting Protocol (CAP), Web Services Notification (WS-N) and Asynchronous Service Access Protocol (ASAP) standards. OGC works with the groups responsible for these standards to harmonize them with the SWE standards.

4.2 Imaging Sensors

The SWE sensor model supports encoding of all the parameters necessary for characterizing complex imaging devices such as those on orbiting earth imaging platforms. ISO and OGC have cooperated to develop two ISO standards that are relevant to the SWE effort: ISO 19130 Geographic Information – Sensor and Data Model for Imagery and Gridded Data and ISO 19101-2 Geographic Information – Reference Model – Imagery (OGC Abstract Specification, Topic 7). Other related work for support of imaging sensors within the SWE context include: OpenGIS® Geography Markup Language (GML) Encoding Standard, GML Application Schema for EO Products Best Practices Paper (OGC Document 06-080r2), OpenGIS® GML in JPEG 2000 for Geographic Imagery Encoding Standard and OpenGIS GML Encoding of Discrete Coverages Best Practices Paper (OGC Document 06-188r1).

5 Current Implementation Efforts

Below are descriptions off some current SWE implementation efforts.

5.1 NASA

Adopting sensor webs as a strategic goal, the U.S. National Aeronautics and Space Administration (NASA) has funded a variety of projects to advance sensor web technology for satellites. A number of these projects have adopted the OGC's Sensor Web Enablement (SWE) suite of standards. Central to many of these efforts has been the collaboration between the NASA Jet Propulsion Lab and the NASA Goddard Space Flight Center (GFSC) using the Earth Observing 1 (EO-1) and assorted other satellites to create sensor web applications which have evolved from prototype to operational systems.

In the OWS-4 test bed activity, GSFC, Vightel Corp., and Noblis initiated a sensor web scenario to provide geographic information system (GIS)-ready sensor data and other infrastructure data to support a response to a simulated wildfire emergency. One of the satellites used in the demonstration was NASA's EO-1, which had the nearest next in-time view for the target, and so provided the real-time data used. An OWS-4 team prototyped the preliminary transformation to SWE implementation using the Open Source GeoBliki framework they developed for this purpose. Both JPL and GSFC are in the process of changing the remaining EO-1 interfaces to OGC SWE compatibility. Figure 5 shows some of the other missions that have begun to adapt portions of the standard. NASA is using the SWE standards to standardize and thus simplify sending commands to satellites.

5.2 SensorNet®

SensorNet®[3] is a vendor-neutral interoperability framework for Web-based discovery, access, control, integration, analysis, exploitation and visualization of online sensors,

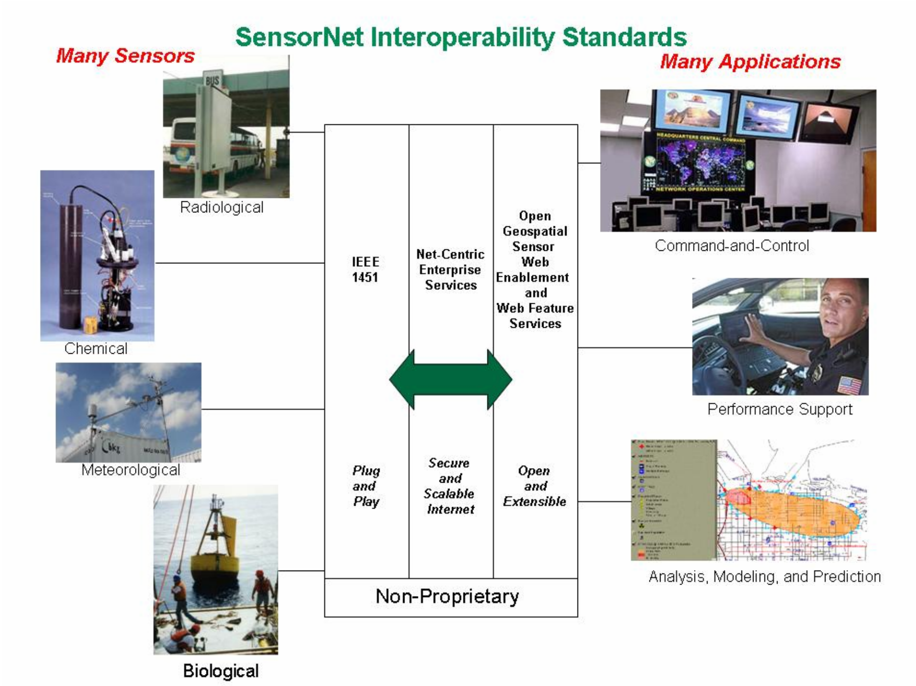
[3] http://www.sensornet.gov

(NASA images)

Fig. 5. All of these satellite and airborne sensors are, at least some of the time, using SensorML for geolocation and other purposes. See NASA's JPL and GSFC Sensorweb/EO-1 pages, http://sensorweb.jpl.nasa.gov/ and http://eo1.gsfc.nasa.gov/ .

transducers, sensor-derived data repositories, and sensor-related processing capabilities. It is being designed and developed by the Computational Sciences and Engineering Division at Oak Ridge National Laboratory (ORNL), in collaboration with the National Oceanic and Atmospheric Administration (NOAA), the Open Geospatial Consortium (OGC), the National Institute for Standards and Technology (NIST), the Institute of Electrical and Electronics Engineers (IEEE), the Department of Defense, and numerous universities and private sector partners. The purpose of SensorNet is to provide a comprehensive nationwide system for real-time detection, identification, and assessment of chemical, biological, radiological, nuclear, and explosive hazards.

The SensorNet team is developing prototypes based on standards and best practices to network a wide variety of sensors for strategic testbeds at military installations, traffic control points, and truck weighing stations. The sensor networks will be connected by secure and redundant communication channels to local, regional and national operations centers. These network testbeds will provide a basis for interfaces to 911 centers, mass notification networks, automated predictive plume modeling applications and evacuation models.



(Image courtesy of ORNL)

Fig. 6. SensorNet lays the groundwork for rapid deployment of a nationwide real-time detection system

5.3 HMA in Europe

The European Space Agency and various partner organizations in Europe are collaborating on the Heterogeneous Mission Accessibility (HMA) project. HMA's high-level goals include consolidating earth imaging and other geospatial interoperability requirements; defining interoperable protocols for cataloging, ordering, and mission planning; and addressing interoperability requirements arising from security concerns such as authorization and limiting reuse. HMA involves a number of OGC standards, including the Sensor Planning Service, which supports the feasibility analysis requirements of Spot Image optical satellite missions (Figure 7).

5.4 Northrop Grumman's PULSENet

Northrop Grumman Corp. (NGC) (http://www.northropgrumman.com) has been using the SWE standards in a major internal research and development (IRAD) project called Persistent Universal Layered Sensor Exploitation Network (PULSENet) (Figure 8). This real-world test bed's objective is to prototype a global sensor web that enables users to:

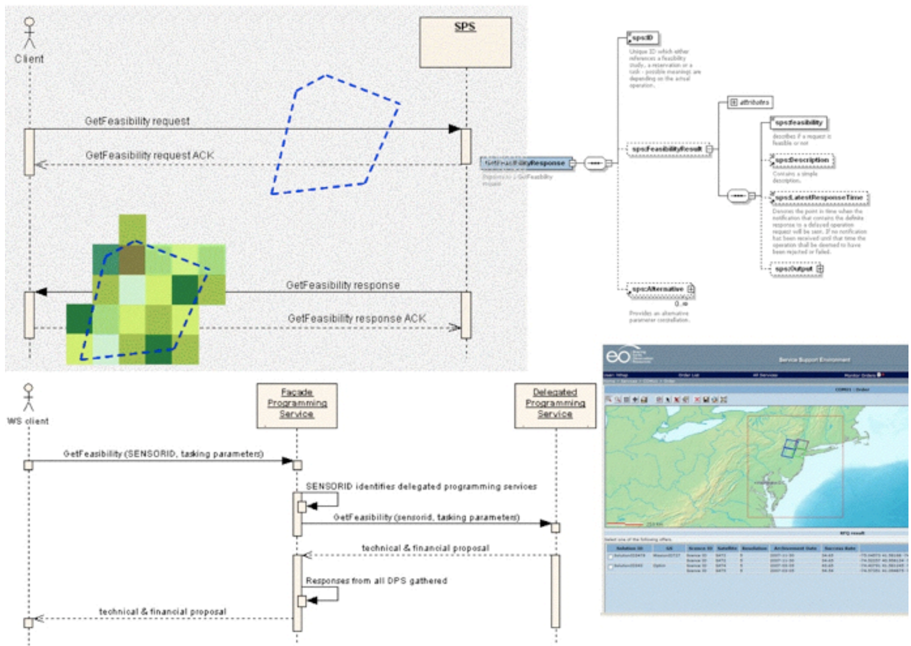


Image courtesy of ESA

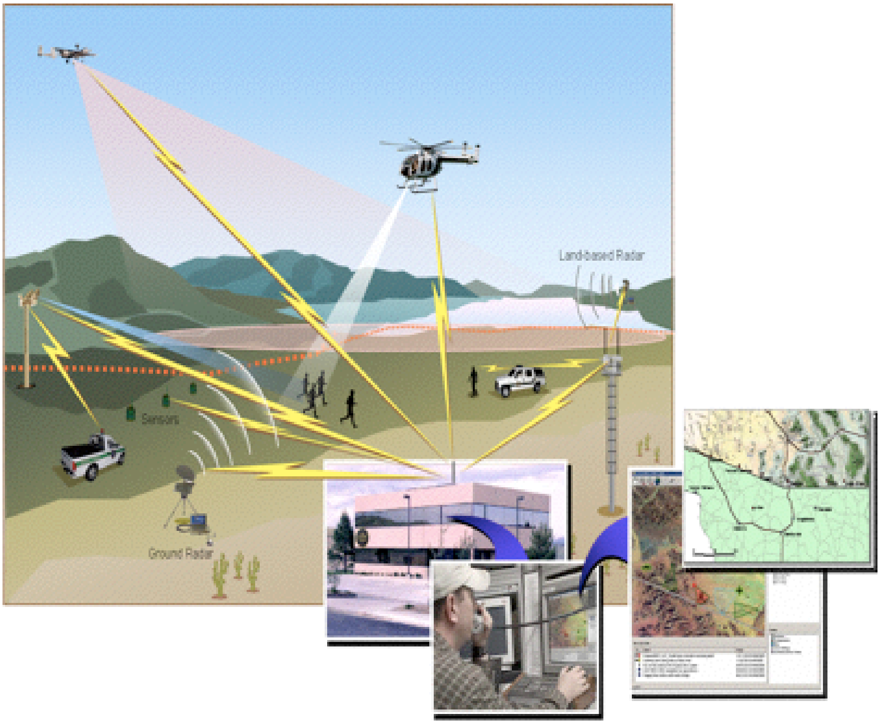
Fig. 7. SPS GetFeasibility operation in a single and multiple satellite environment

- Discover sensors (secure or public) quickly, send commands to them, and access their observations in ways that meet user needs
- Obtain sensor descriptions in a standard encoding that is understandable by a user and the user's software
- Subscribe to and receive alerts when a sensor measures a particular phenomenon

In its first year, PULSENet was successfully field tested under a real-life scenario that fused data from four unattended ground sensors, two tracking cameras, 1,800 NOAA weather stations and the EO-1 satellite.

5.5 SANY Sensors Anywhere

SANY IP (http://www.sany-ip.org/) (Figure 9) is co-funded by the Information Society and Media Directorate General of the European Commission. SANY IP intends to contribute to Global Monitoring for Environment and Security (GMES, a major European space initiative), and the Global Earth Observation System of Systems (GEOSS) by developing a standard open architecture and a set of basic services for in situ sensor integration of all kinds of sensors, sensor networks, and other sensor-like services. It aims to improve the interoperability of in-situ sensors



(Image courtesy of Northrop Grumman)

Fig. 8. PULSENet clients in multiple Web locations can task heterogeneous sensors and sensor systems

and sensor networks and to allow quick and cost-efficient reuse of data and services from currently incompatible sources for future environmental risk management applications. Though SANY addresses interoperability in monitoring sensor networks in general, it focuses on air quality, bathing water quality, and urban tunnel excavation monitoring.

The SANY Consortium recognizes the OGC's SWE suite of standards as one of the key technologies that can eventually lead to self-organizing, self-healing, ad-hoc networking of in situ and earth observation sensor networks. Earlier this year, SANY evaluated the capabilities of SWE services with the intention of actively contributing to further development of the SWE standard specifications. As reported at the OGC TC meeting in Ispra (December 2007), the SANY Consortium has described the common architecture used in SANY baseline applications; included architectural requirements inherited from ORCHESTRA, GEOSS, etc.; and published a road map for v1, v2, and v3 versions of the architecture.

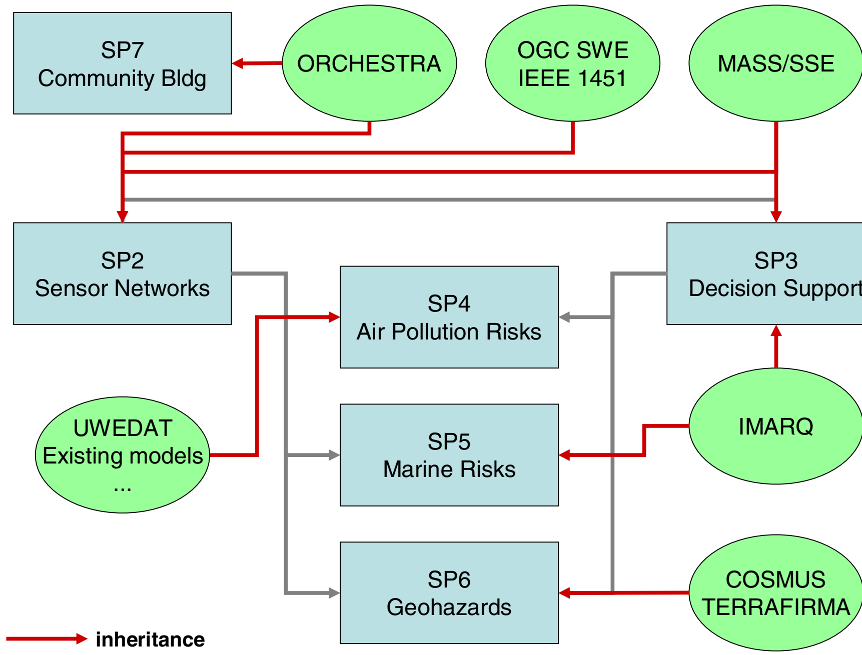


Fig. 9. SANY project inheritance and activities. (Image from an Enviroinfo 2006 article, Denis Havlik et al, "Introduction to SANY (Sensors Anywhere)Integrated Project" In: Klaus Tochtermann, Arno Scharl (eds).

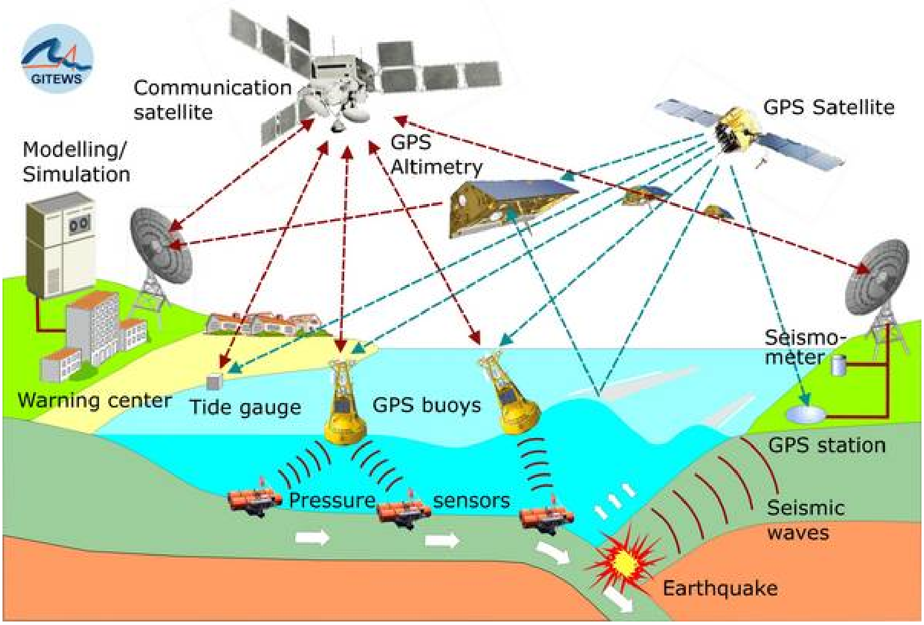
5.6 52North

The German organization 52°North provides a complete set of SWE services under GPL license. This open source software is being used in a number of real-world systems, including a monitoring and control system for the Wupper River watershed in Germany and the Advanced Fire Information System (AFIS), wildfire monitoring system in South Africa.

One of several research projects using 52°North's software is the German Indonesian Tsunami Early Warning System (GITEWS) (Figure 11), a 35-million-euro project of the German aerospace agency, DLR, and the GeoForschungsZentrum Potsdam (GFZ), Germany's National Research Centre for Geosciences. GITEWS will use SWE services as a front-end for sharing Tsunami-related information among the various components of the GITEWS software itself. GITEWS uses real-time sensors, simulation models, and other data sources, all of which must be integrated into a single system. SANY, mentioned earlier, is also using 52°North's software.

5.7 Access to U.S. Hydrologic Data

The Consortium of Universities for the Advancement of Hydrologic Science Inc. (CUAHSI) is an organization founded to advance hydrologic research and education



(Image courtesy of GITWS)

Fig. 10. German Indonesian Tsunami Early Warning System (GITEWS) components

by organizing and supporting university-based collaborative projects. CUAHSI represents more than 100 U.S. universities, as well as international affiliates, and is supported by the U.S. National Science Foundation. Its Hydrologic Information System (HIS) project involves several research universities and the San Diego Supercomputer Center as the technology partner. For three years, the CUAHSI HIS team has been researching, prototyping, and implementing Web services for discovering and accessing different hydrologic data sources, and developing online and desktop applications for managing and exploring hydrologic time series and other hydrologic data.

The core of the HIS design is a collection of WaterOneFlow SOAP services for uniform access to heterogeneous repositories of hydrologic observation data. (SOAP is a protocol for exchanging XML-based messages over computer networks. SOAP forms the foundation layer of the Web services stack, providing a basic messaging framework that more abstract layers can build on.) The services follow a common XML messaging schema named CUAHSI WaterML, which includes constructs for transmitting observation values and time series, as well as observation metadata including information about sites, variables, and networks. At the time of writing, the services provide access to many federal data repositories (at USGS, EPA, USDA, NCDC), state and local data collections, as well as to data collected in the course of academic projects. The HIS Server, which supports publication of hydrologic observations data services, is deployed at 11 NSF-supported hydrologic observatories across the country and a number of other university sites (Figure 11).

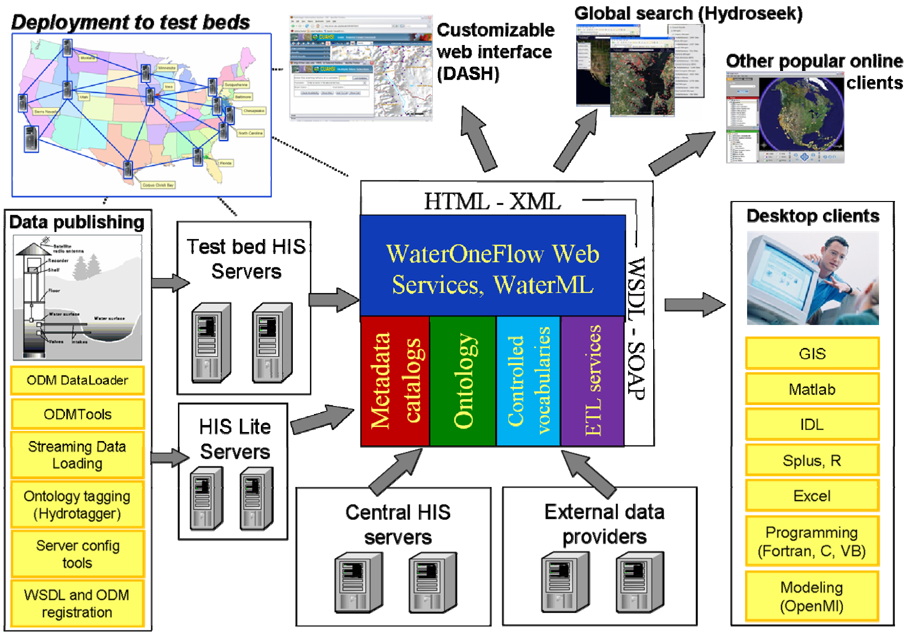


Image courtesy of CUAHSI.

Fig. 11. WaterOneFlow Web services will provide a standard mechanism for flow of hydrologic data between hydrologic data servers (databases) and users

The WaterML specification (Figure 11) is available as an OGC discussion paper (document 07-041). The CUAHSI HIS team is working with OGC to harmonize it with OGC standards such as GML and the OGC Observations and Measurements specification to make the next version of CUAHSI Web services OGC-compliant. The project's web site is www.cuahsi.org/his. The project is supported by NSF award EAR-0622374, which is gratefully acknowledged.

6 Conclusion

OGC's SWE standards have the potential to become key parts of an integrated global framework for discovering and interacting with Web-accessible sensors and for assembling and utilizing sensor networks on the Web. OGC invites additional participation in the consensus process and also invites technical queries related to new implementations of the emerging standards.