Commentary

Environmental Sensor Networks*

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This report is based on the Fall Meeting's Special Focus: Advances in Data Acquisition, Management, Analysis and Display - Cyberinfrastructure for Earth Systems Science IV: Sensor Networks. An Environmental Sensor Network comprises an array of sensors which gather data autonomously and automatically forward the data to a central server. What differentiates modern sensor networks from previous techniques are an emphasis on "intelligence" in the sensor packages as well as the data network. They also typically publish the data on the server to the World Wide Web and allow real-time access to the data. These networks require a unique combination of technological and environmental understanding, and have the potential of creating a revolution in environmental monitoring, similar in impact to satellite remote sensing in the 1970's.

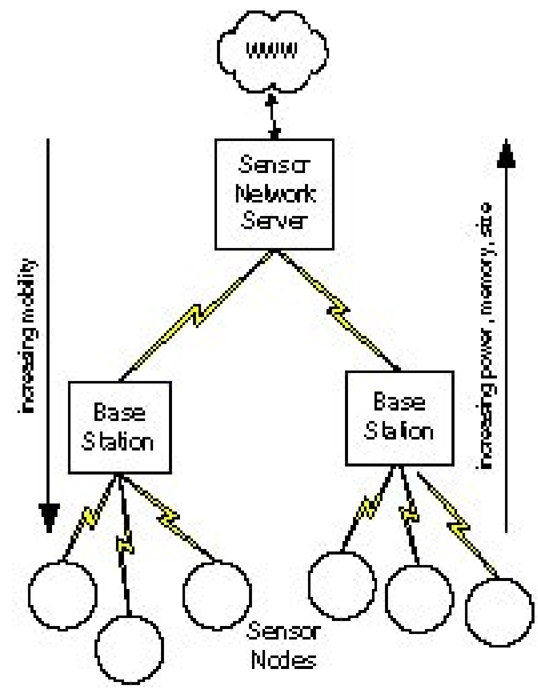

Figure 1. Schematic diagram to show an Environmental Sensor Network

Within an Environmental Sensor Network, the sensor nodes gather data autonomously and a network is used to pass the data to one or more base stations (Figure 1). While wired networks can be used, for many applications the aim is to move towards a wireless networks (as wire is expensive, obtrusive and can disturb the environment being monitored). Where the sensor nodes dynamically intercommunicate in order to establish a network this is termed an *ad-hoc network*. Different types of data are collected by the sensor nodes. This includes specific environmental parameters (e.g. soil moisture, stress, tilt) as well as generic data such as meteorological or dGPS. This data can be in different forms, digital and analogue, spatial and temporal, database or image, fixed or moving. At the server level the data can be visualised and analysed within a GIS system, combined with a satellite image and/or map, and published via the web to give researchers seamless access to information.

In some remote or hazardous environments, data on basic environmental processes can be measured for the first time. In addition, sensor nodes can store data (to be released on instruction), make decisions about what data to pass on (e.g. local area summary) and even make decisions about when and what to sense (when conditions are appropriate). The network may be able to respond to data sent by the sensor nodes and act as a vital hazard warning system, e.g. if an oil spill happens or weather forecast suggests a storm will occur then the nodes can switch on or change their behaviour. The aim of future sensor networks, would be the monitoring of the environment at all scales, where the data was automatically forwarded to the web where it would be integrated and analysed with different data sets within an 'intelligent' cyberinfrastructure.

The development of Environmental Sensor Networks (which have evolved from automated loggers that record data at specific intervals and require manual downloading by a maintenance team) has occurred because of the miniaturisation of electronics and wireless technology. In particular, Chong and Kumar (2003) have argued that sensor networks integrate research advances from sensors, communication and computing, however in addition to this, Martinez *et al*., (2004) have argued that understanding environmental processes is the vital fourth component in sensing the environment. Sensor nodes need to be low-cost (so that many can be deployed to sense the environment at a small scale)), low power (otherwise they do not run without constant battery maintenance), robust (due to the hostile nature of most environments), non-polluting and preferably blend into the environment. They also need to be specifically designed for the environment they are sensing. They need to at the appropriate scale, record the necessary environmental parameters at a suitable time interval, and if possible behave like a natural part of the environment e.g. the GLACSWEB project (Martinez *et al*., 2004) which is sensing glacier behaviour, uses sensors embedded in a probe shaped like a clast and the Berkeley habitat modelling at Great Duck Island, which is analysing birds nesting habits uses camouflaged nodes in birds burrows (Szewczyk *et al*., 2004a). In the future, sensors on a sub-millimetre scale (*Smart dust* - Kahn *et al*., 2000) may be available to monitor water flow patterns or quality.

However, new data collection methods can generate their own research problems. One inevitable consequence of continuous data from numerous sensor nodes is the generation of enormous amounts of data. This will need to be handled within a GIS and/or cyberinfrastructure system which allows other systems to find out what type of data is available and how to get it automatically. This is where Semantic Web technologies (http://www.w3.org/2001/sw/) will be indispensable, as common ontologies can evolve which will help to unify differently named data on the servers. In principle this would allow a sensor network to fetch weather data from a completely different provider and allow researchers to have one view of data even though it comes from many sources.

The AGU Fall Meeting 2004 provided an opportunity to present results from sensor networks from different scales and environments. This was one of the first times that researchers have discussed this new theme within a general geoscience conference, prior to this some projects reported technical aspects at recent inaugural conferences, e.g. The 1st ACM Conference on Embedded Networked Sensor Systems 2003; The 1st IEEE Communications Society Conference on Sensor and Ad Hoc Communications and Networks 2004; whilst the environmental aspects have been discussed within their separate subject fields. So it was the first time that both speakers and audience had a chance to meet, listen and share ideas outside their own immediate research area. The session had an unusual name, but still generated an impressive audience.

The session brought together researchers working on the technological aspects of sensor networks as well as practitioners. The session was introduced by Kevin Delin from NASA JPL with a summary of his pioneering research on sensor webs from different environments (from Huntington Gardens, Antarctica and future Mars projects) (Delin, 2004). He outlined the advances in sensor networks research as well as the challenges.

Dr Jonathon Lees (University of North Carolina), spoke on a wireless sensor network of seismic stations for Volcano monitoring from Tungurahua, Ecuador. They showed how an array of inexpensive geophones could be used as a volcano hazard alert system. On a similar small scale, Dr Kirk Martinez (University of Southampton, UK) described the GLACSWEB project which uses sensor nodes inserted beneath the ice which record stress, tilt, temperature and water pressure to understand glacier dynamics (as so understand glacier response to climate change). On the medium scale, Prof. Richard Holmen (Oregon State) described the Argus video system for nearshore monitoring. This system clearly illustrates the evolution from passive logging to an active Environmental Sensor Network which began as simply video recording in 1992 but now is using the intelligent processing of images since data reduction is necessary within the sensor network because otherwise video data would overload the communications infrastructure. This system provides exciting new data to understand near shore wave processes.

The session was concluded by George Thomas (University of Washington) describing large scale monitoring projects such as the Tropical Atmosphere Ocean Project to monitor the El Niño, and The Pacific Northwest Seismograph Network to monitor seismology around Mount Helen. Although these systems are not currently *ad hoc* sensor networks, they have the potential to be networked in a more 'intelligent' way now that the expensive infrastructure (fixed buoys, etc) has been installed.

It was clear from the sessions, that there is a need to collect basic data about many environments, since this has not previously been available; as well as more focused data collection and data for hazard alerts. Although this field is only in its infancy, significant first steps have been made, and many generic problems solved/shared. In particular, projects are now up and running using both off-the-shelf and custom designs; and the tough challenges of power management and communications have been investigated and are now better understood.

It is hoped that this is the first of many such meetings, and we thank the AGU organisers for accepting our special session, and the speakers for their contributions, and the participants for making this such an exciting inaugural.

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