Environment, Water and Sustainability

The National Weather Sensor Grid

Innovative Sensor Grid Design Enables Large-Scale Intelligent and Pervasive Environmental Monitoring

By Dr Lim Hock Beng, Dr Wang Wenqiang, Mr Mudasser Iqbal, Ms Yao Yuxia

In recent years, news and articles regarding global climate and environmental changes appear in the media more and more frequently. Scientists, government leaders and even ordinary citizens worldwide are increasingly concerned about global warming, El Niño, melting of polar ice caps, the rising sea level and other phenomena caused by global climate and environmental changes.

Large-scale environmental monitoring networks are important tools to study global climate change and its impact on ecosystems and civilizations. Some of these monitoring networks, such as the early Tsunami warning systems deployed in the Pacific and Indian oceans, can be crucial for saving human lives.

With rapid advancement in technology, building such networks has become easier than before. For example, environmental monitoring sensors are becoming smaller, cheaper and more powerful, and they can be deployed in the most hazardous environments on Earth. Long range real-time data transmission has become possible with emerging wireless technologies.

As an island country, Singapore is vulnerable to the hazardous consequences of global climate change. Environmental issues are rapidly coming to the forefront of national concerns and public consciousness.

Senoko Power, Singapore's largest power generation company, initiated the National Weather Study Project (NWSP) in 2006. It is a community-based initiative that aims to promote the awareness about climate change, global warming and the environment among the youth population of Singapore. Senoko Power provided each participating school with a mini weather station for the school students to undertake various weather and environmental study projects. Figure 1 shows the deployment of weather stations in several schools.

Figure 1: Deployment of weather stations in schools throughout Singapore

A research team from the NTU Intelligent Systems Centre (IntelliSys) is building the National Weather Sensor Grid (NWSG) as the key infrastructure for the NWSP. The NWSG connects all of the school weather stations, so that the weather data can be automatically collected in real time and stored in a Central Data Depository (CDD) for subsequent data processing, analysis and sharing.

This system helps students and teachers to enhance the scope and depth of their weather study projects. More importantly, it provides a test bed for the development of large-scale environmental monitoring networks with significant research and industrial impact.

The Principal Investigator of this project is **Dr Lim Hock Beng (Program Director, IntelliSys)**. The other team members are **Dr Wang Wenqiang (Research Fellow)**, **Mr Mudasser Iqbal (Research Engineer)**, **Ms Yao Yuxia (Research Engineer)** and several undergraduate research students and interns. The project is funded by Microsoft Research, IntelliSys and the NTU Research Support Office.

What is the National Weather Sensor Grid?

The National Weather Sensor Grid (NWSG) is a large-scale infrastructure for intelligent and pervasive environmental monitoring. It is based on two important and promising technologies; namely, sensor networks and grid computing.

Sensor networks are collections of sensor nodes connected via wired or wireless networks for sensing and measuring the physical environment. They present many challenging research issues and they have a wide range of important applications such as environmental and weather monitoring, military surveillance and homeland security, healthcare monitoring, tracking of manufacturing processes, smart homes and offices, etc. Thus, sensor networks have attracted a great deal of interest in the research community as well as within the industry.

Grid computing is an established standards-based approach for the coordinated sharing of distributed and heterogeneous resources. A compute grid provides distributed resources to meet the computational requirements of applications, while a data grid provides seamless access to large amounts of distributed data and storage resources.

For large-scale sensing applications, it is a major challenge to collect and share real-time data from heterogeneous sensor networks and sensor devices distributed over a wide area, and to process these data to make intelligent decisions. A promising approach is the integration of sensor networks with existing IT infrastructures such as the Internet to form cyber-sensor infrastructures for sensor data collection and management.

Sensor grids, which combine sensor networks with grid computing, are good building blocks for large-scale cyber-sensor infrastructures. By integrating and sharing various sensor, computational and storage resources distributed geographically, the sensor grid enables the collection, processing, sharing, visualization, archival and searching of large amounts of real-time sensor data.

"To our knowledge, the NWSG is the first implementation of a large-scale sensor grid for environmental monitoring. The novelty of the NWSG lies in its ability to integrate multiple sensor deployments, computational resources and storage resources owned by different organizations across a wide geographical area, and to make the sensor data seamlessly accessible for sharing, analysis, and decision making. These are the key elements for designing large-scale intelligent and pervasive environmental monitoring systems," says Dr Lim.

NWSG Architecture and Middleware Framework

The design of sensor grids requires a comprehensive framework to address challenges such as connectivity, scalability, resource scheduling, data management, security, availability, quality of service, etc. We have developed a sensor grid architecture framework called the Scalable Proxy-based aRchItecture for seNsor Grid (SPRING). By using proxy nodes as interfaces between sensor networks and the grid fabric, the SPRING framework is scalable and it can integrate heterogeneous sensor networks and devices with the grid.

The NWSG is built upon the SPRING framework and has several important features. First, it connects all the weather stations via the Internet to automatically collect and aggregate weather data in real-time. Second, the weather data are logically stored in the CDD, which uses distributed data storage resources. Third, the NWSG integrates computational resources for the compute-intensive processing of weather data. Fourth, the weather data can be conveniently accessed and shared via the web through mash-ups, blogs, and other user applications.

Figure 2 shows the system architecture and components of the NWSG. A Virtual Organization (VO) is a resource-sharing participant of a sensor grid. In the NWSG, the schools and other organizations deploying the weather stations and grid infrastructure hosting sites are considered as VOs. A VO may own one or more resources such as sensor resources, computational data resources, grid-enabled devices, etc.

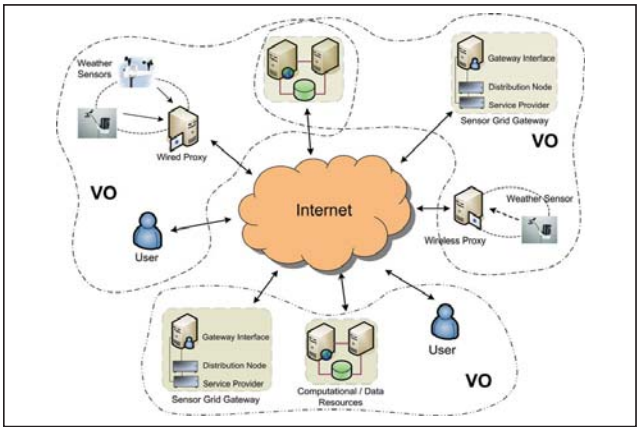

Figure 2. NWSG system architecture

Each VO can access and use resources in other VOs through distributed resource brokerage and user authentication. The weather sensors are connected to the NWSG via wired or wireless proxy nodes. Users can schedule sensor data collection jobs on programmable weather sensors in any VO. Users and applications can also share and access archived or real-time weather data, and to run sophisticated weather data processing jobs using the necessary amount of sensor and computational resources in different VOs.

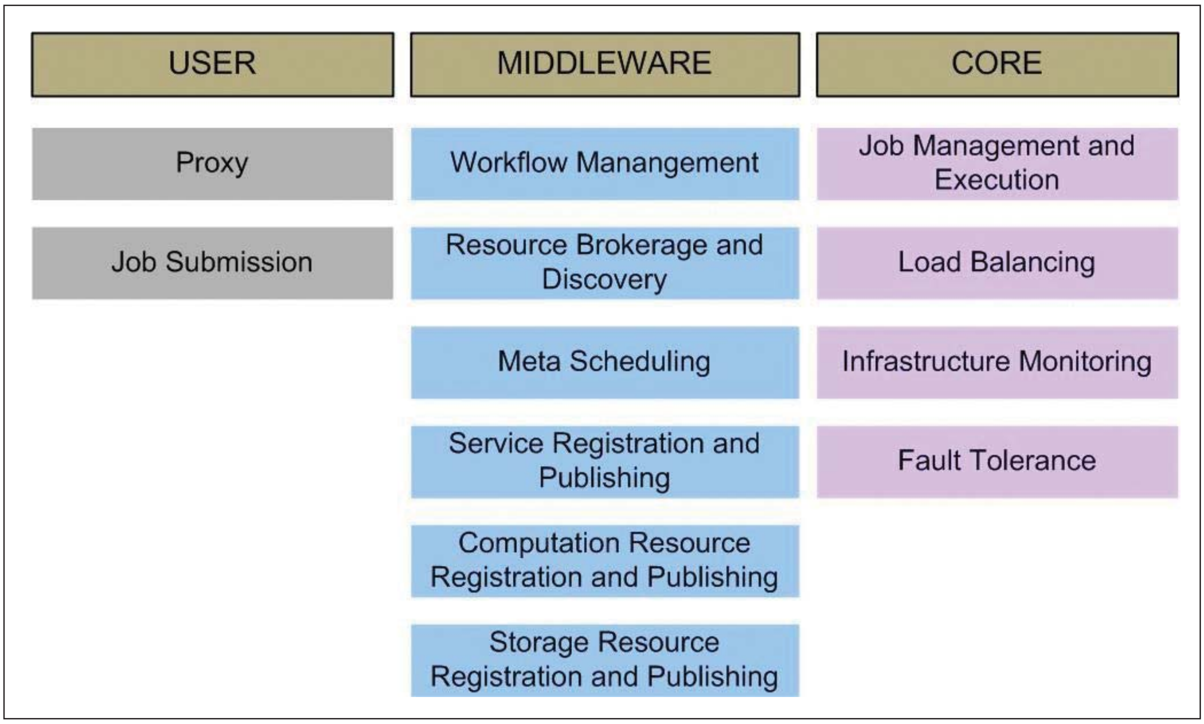

Figure 3. NWSG software architecture

The key enabling component of this distributed resource access is the sensor grid gateway. Since access to heterogeneous resources requires discovery, authentication, scheduling and execution of user requests, the sensor grid gateways maintain VO-level meta-information and implement the middleware needed to integrate sensor networks with the grid fabric. The user level, middleware and core services that form the NWSG software architecture are illustrated in Figure 3.

NWSG Software and Web Services

We are developing tools and services to efficiently publish, query, process, visualize, archive and search the vast amount of weather data. Web interfaces are provided to enable public access to the NWSG and its services. The public weather portal that hosts the NWSG services is accessible at http://nwsp.ntu.edu.sg.

We use geo-centric web interfaces to display and visualize the weather station information such as the geographical location, operational status, weather data sampling frequency and data snapshot, etc. The two interfaces developed so far are based on Microsoft SensorMap and Google Earth. Sample screen shots of the weather station map using the SensorMap and Google Earth interfaces are shown in Figures 4 and 5 respectively.

In particular, the Microsoft SensorMap is a specialized platform for sensor information publishing. We obtained a research award from Microsoft Research and started a collaboration project with them to develop tools for sensor data publishing and querying using the SensorMap platform. This project is led by **Dr Lim Hock Beng (Principal Investigator, IntelliSys)** and **Dr Ling Keck Voon (co-Principal Investigator**, **School of Electrical and Electronics Engineering).**

Figure 4. Weather station map on Microsoft SensorMap

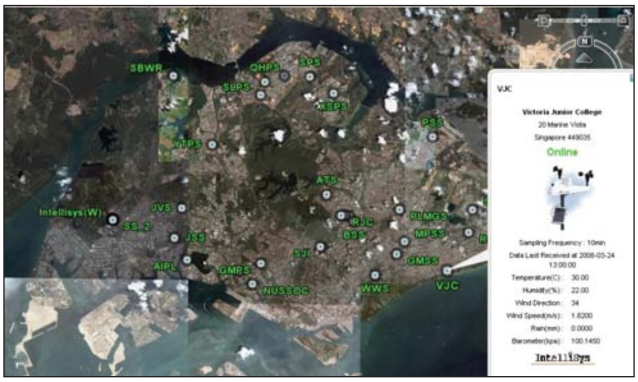

Figure 5. Weather station map on Google Earth

We have also developed a dynamic weather data display based on Macromedia Flash as shown in Figure 6. It is customizable since users can select the weather station to be displayed. In the spirit of Web 2.0, this display can be embedded within any web site, blog, or web-based application. This allows us to easily disseminate the weather data to users.

Figure 6. Dynamic embeddable weather display

A data download service and interface has been developed to enable the users to download the weather data for research and educational purposes. Users can specify the desired weather station, time period, weather parameters and data format to download the data.

To visualize the temporal variations in weather conditions at a particular weather station, we provide a graphical plot service as shown in Figure 7. Users can select the weather station and the weather parameter, and a graphical plot will be displayed. In addition, various weather statistics such as the maximum, minimum and mean values of the selected parameter are computed via grid services and displayed.

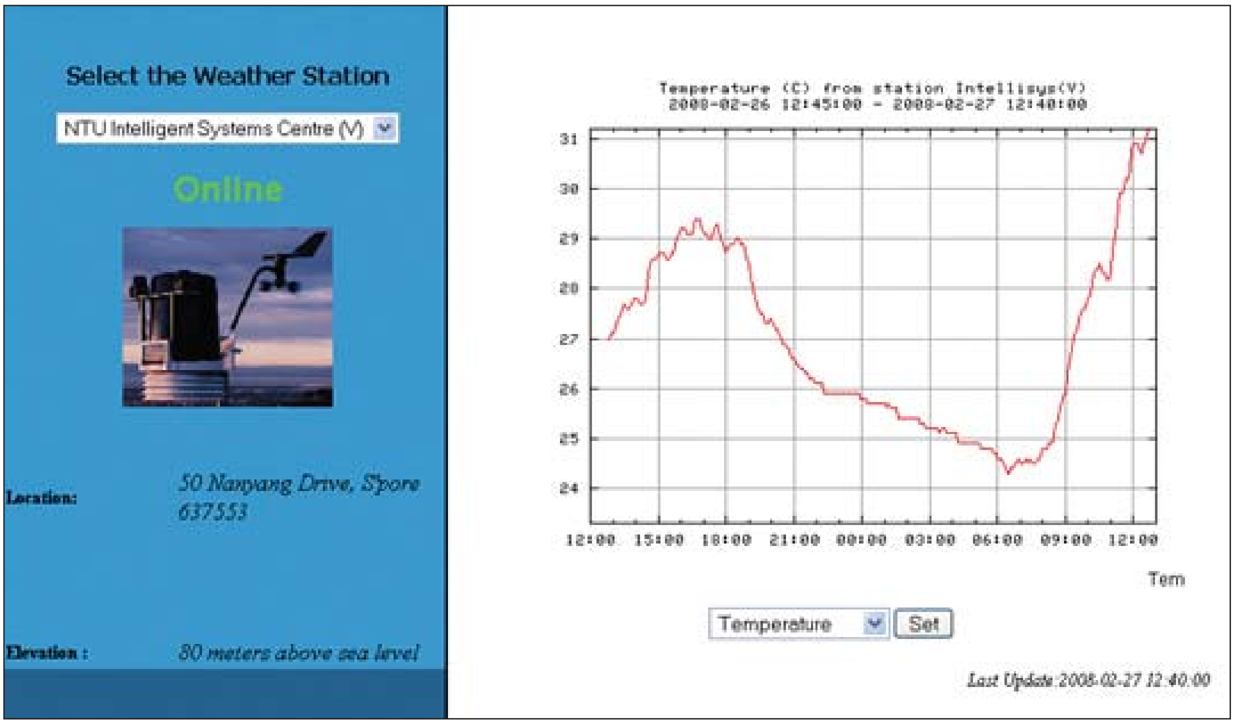

Figure 7. Graphical weather data plot

We also developed several useful grid services based on the NWSG infrastructure. For example, a zone-based weather statistics grid service enables the user to query weather conditions over a geographical zone with multiple weather stations. After the user selects the zone of interest, the grid service then discovers the weather stations from which data must be acquired and analyzed to compute zone-based weather statistics for the user. A Weather Alerts grid service has been provided for users to receive notifications of specific weather events. For example, users can receive email notifications when it starts and stops raining at a location.

Research and Industrial Impact

Apart from weather stations, we can extend the NWSG infrastructure to manage a wide variety of sensors, such as water quality sensors, air quality sensors, seismic stations, GPS stations, traffic cameras, security cameras, etc. This enables the NWSG to support many important applications.

Environmental and water technologies are among the new growth sectors of the Singapore economy. One of the key research and development areas on water technologies is water quality management. At present, water quality sensors are already deployed in some of the catchments, rivers, canals, and reservoirs to monitor certain water quality parameters. The NWSG can be used to integrate such sensor deployments throughout Singapore so that extensive water quality data can be collected nationwide and managed on a unified platform. Apart from water quality monitoring, such a system can also enhance water security by supporting the detection of contaminants in the nation's water supply and providing decision support to mitigate contamination events.

For countries to adhere to the Kyoto protocol, measuring and controlling the emission of greenhouse gases has become a critical issue world-wide. In Singapore, the bulk of the greenhouse gases, such as CO_2 and SO_2, is emitted from power plants and industrial plants. Air quality and chemical sensors can be used to measure the gas emissions from such plants. The NWSG can integrate such sensors deployed throughout Singapore to enable automatic real-time monitoring and auditing of the gas emissions.

Clean energy is another important direction to address the climate change problem. Solar power and wind power are popular clean energy alternatives. In order to efficiently harness solar power in Singapore, it is necessary to analyze the distribution of solar energy locally. The NWSG can collect data from a large number of weather stations equipped with solar radiation sensors to generate a detailed spatial and temporal distribution of the solar intensities in Singapore. This can facilitate the selection of suitable sites for the installation of solar power plants.

Although Singapore is lucky to be relatively free from major natural hazards like earthquakes, volcanic eruptions, tsunamis and extreme climate changes, we are still affected by the increasing occurrences of such hazards in Southeast Asia. For example, recent earthquakes in Sumatra can be felt in Singapore. Scientists are concerned that an extremely powerful earthquake could strike Sumatra in future, and this event may indirectly affect Singapore. The Earth Observatory of Singapore (EOS), a Research Centre of Excellence (RCE) in earth sciences at NTU, will deploy seismic sensors, Continuous GPS (cGPS) stations and other sensors to monitor the Sumatran fault. Such sensor deployments for earth sciences can be integrated by sensor grids to enable reliable and robust sensing, data acquisition, analysis, dissemination and visualization.

We anticipate that large-scale deployments of sensor grids will be carried out for various application domains in the coming years. The NWSG has the potential to be an important component of large-scale intelligent and pervasive sensing systems with significant research and industrial impact.

For more information and to explore opportunities for collaboration, contact Dr Lim Hock Beng at limhb@ntu.edu.sg.

Water Treatment

Development of environmental friendly self-cleaning 'flakes' to treat water

Using a combination of ultraviolet (UV) light and filters with atomic-sized pores, a team led by **Assoc Prof Darren Sun** from **School of Civil and Environmental Engineering (CEE)** and with scientists from Stanford University have developed self-cleaning membranes, a technology that saves almost 90 percent of the energy used in conventional water treatment methods.

The material, which is made up of nanofibers, will "stick" to existing water treatment membranes, where it attracts impurities in raw water. With its atomic sized nano pores, water is ultra-filtered before going on to further treatment. When UV light is passed over it, the film, which acts as a catalyst will destroy contaminants on its surface. These are then released as carbon dioxide and other harmless mineral products.