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Research on the framework of the Environmental Internet of Things

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Higher urbanization rates cause new urban environmental problems and changing trends. New technologies also provide novel techniques for environmental management. This paper establishes a framework for an Environmental Internet of Things (EIoT) and describes key technologies, including Wireless Sensor Network (WSN), network techniques, Geographic Information System (GIS), WebGIS, and distributed database techniques. The framework of the EIoT from bottom to top includes environmental sensors, real-time network monitoring system, environmental databases, environmental information platform, and environmental management system. We discuss the construction of our EIoT and show how it provides real-time monitoring at the residential level of environmental factors such as water, soil, atmosphere, noise, and wind. The EIoT can also realize online environmental simulation and management and is currently being extended to the city, regional, and national levels. The EIoT can improve understanding of the urban environment and help to provide advanced technological solutions for increasingly serious environmental problems.

Keywords: urban environment; Environmental Internet of Things; framework; Wireless Sensor Network; information platform

1. Introduction

While the world entered the urban society age in 2008 (Zhao et al. 2010), China's rate of urbanization reached 50% in 2012, nearly three times higher than the level in 1978 when the policy of economic reform and opening-up began (Niu 2012). Rapid industrialization and urbanization require the initiation and promotion of the science or the study of urban environment, to find a way to integrate or couple urban development and eco-environment processes for sustainable cities (Zhao et al. 2008). The development of the Environmental Internet of Things (EIoT) will be beneficial to the development of the science or the study of urban environment and to environmental management (Zhao Forthcoming 2013).

Higher urbanization rates have led to closer links between cities. Population growth and economic development have shown a notable trend to regionalization (Xiao & Yuan 2009). Urban environmental problems are also becoming regional in nature (Liu & Fang 2008; Wang et al. 2012). The arrival of the networked information era has resulted in the emergence of the 'digital city' (a connected community within the city that combines Information and Communication Technologies infrastructure) (Ergazakis et al. 2011). Urban environmental problems have also presented new features and changing trends, but their inter-related nature exacerbates the difficulty of environmen-

tal analysis, management, and protection. Conventional technology for environmental monitoring, simulation, and management seems to be isolated and inadequate at both temporal and spatial scales. The adoption of advanced technology and digital and networking methods in the study of urban environmental problems would be a major step forward in cognizing, analyzing, and solving increasingly serious urban environmental problems (Delin 2002).

The Internet of Things (IoT) refers to a huge network that includes the Internet and many kinds of sensor equipments, including radio frequency identification (RFID) devices, infrared sensors, Global Positioning System, and laser scanners (ITU 2005; Amardeo & Sarma 2009). By making everything connected to the Internet, the system enables automatic identification, positioning, tracing, and monitoring in real time.

IoT applications are very extensive and include fields such as the smart grid (Lin et al. 2009), smart transportation (Doli 2006), smart logistics (Yan & Huang 2008), and e-health (Frederix 2009). At present, there are only preliminary applications in the environmental field, such as the online monitoring of pollutant sources and indoor environmental monitoring systems. However, the EIoT is dealing with the environmental sciences and has many potential applications in environmental monitoring, simulation, and management.

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Our research group started to investigate and develop the EIoT for the Long-term Urban Ecosystem Observation and Research Station in Xiamen City (Xiamen LUEORS) in 2007, under the direction of Professor Jingzhu Zhao. These efforts over several years have led to the establishment of an EIoT, and in following section, we present its main framework.

2. IoT architecture

2.1. IoT concept and principle

Generally, there are three main characteristics of the IoT (Toma et al. 2009). The first is full sensing, meaning that RFID, sensors, and two-dimensional code are used to detect information about things anywhere and at any time. The second is reliable delivery, as information is transmitted through the integration of all kinds of telecommunication networks and the Internet. The third is intelligent processing, during which computing technologies, such as cloud computing and fuzzy recognition, are used to analyze and process massive amounts of data and intelligently control the 'things'. As a result, it is often thought that the IoT is composed of three levels: the sensing layer for collecting the data, the network layer for transferring the data, and the application layer for data processing and analysis.

2.2. Key technologies of the IoT

The IoT is a network information system which combines the distributed technologies of information collection, transmission, and processing. Its characteristics include low-cost, miniaturization, low-power, flexible networking, and suitability for moving targets. The key technologies of the IoT are listed below:

Wireless Sensor Network (WSN). A WSN is a self-organized multi-hop network formed by wireless communication and is composed of a mass of low-cost tiny sensor nodes. Its purpose is to sense, collect, and process information from the sensed objects in the area covered by the network and to send this information to the observer. The sensor node consists of sensor, processor, wireless communication, and energy supply modules. The sensor module is used for information collection and data conversion in the monitoring area. The processor module controls the data that are collected, saved, and processed by all the sensor nodes. The wireless communication module is used for wireless communication with other sensor nodes, the exchange of control information, and the transceiving of collected data. The energy supply module is used to provide energy to run the sensor node (Sun et al. 2005).

High-speed network technology. This technology is used to achieve information sharing, interoperability, and distributed storage and computation of mass data.

Geographic Information System (GIS). GIS is a key technology in the urban environment field, providing a full set of management tools for location-specific environmental data, which can help decision-makers form specific policies. GIS has been widely adopted in the field of environmental protection, including environmental monitoring and assessment, emergency measures for accidental contamination, and environmental messages sharing. WebGIS is a combination of GIS and Web technology and is composed of a database server, application server, and client. The key client component is a browser that provides an interactive interface for users and presents users with the analysis and simulated urban environment results. The application server consists of a Web server and a GIS server. The Web server is used to receive user map requests and forward the request to the GIS server, after which the GIS server processes the request and sends the processing results to the Web server, which sends the results to the users (Meng et al. 2005).

Distributed database technique. This technique provides technical support for mass data processing within the EIoT. One distributed database can effectively realize distributed query and data updating.

The IoT is continually expanding along with the development of the Internet and communications network, and its multi-functionality provides important technical support for environmental monitoring, simulation, and management. By 2020, there will be around 50 billion devices connected to a wireless network, and a large proportion of those devices will be able to reduce carbon emissions and other environmental impacts by virtue of being connected to the Internet (Reuters 2011).

3. EIoT framework

3.1. EIoT datastream

A huge potential for environmental management exists in the expanding IoT. Having so many devices connected to a network will make it easier to control many aspects of daily life that have an impact on the environment and make their use more efficient. EIoT data begin with a network of environmental sensors, real-time environmental monitoring, visualization of environmental information, modeling of environmental analysis, spatialization of environmental management regions, and gridding of urban environmental management regions (Figure 1). The EIoT can then perceive, analyze, and simulate the urban environment, and the simulated results are used to predict the future evolution of the urban environment. In view of the major urban environmental problems arising during the urbanization process in China, the purpose of building the EIoT is to apply wireless sensors and information network techniques to perceive urban environmental elements in real time, use various specialized models to simulate urban environmental changes,

Figure 1. EIoT datastream.

and reveal the major characteristics of the evolving urban environment under different space–time conditions.

3.2. EIoT application

The spatial units of the EIoT framework include nodes, stations, sample plots, cities, and the entire nation, and environmental sensors that have strong sensing capability and real-time functions are adopted to acquire long-term environmental information with high temporal resolution. The monitoring of various environmental factors based on the sensors at multi-spatial scales is shown in Figure 1.

The sensor technology is used to collect and integrate urban environmental information, based on that an efficient, stable, relatively cheap, and energy-efficient sensor network model or system was constructed through the integration and assembly of diversified sensors. The detailed information is described by Su et al. (Forthcoming 2013).

Based on the accumulation, pre-processing, and preliminary analysis of environmental data, we built several environmental models and used networking and digital analysis and visual representation to achieve smart environmental management.

Since the creation of an environmental model requires the support of large amounts of data, we constructed fundamental databases including a basic urban geographic information database and urban infrastructure database. Other datasets which were compiled and stored include land-use changes, water quality, soil environment, acoustic

environment, solid wastes, socio-economic background, ethnic minority cultures, and so on.

The environmental information platform is based on mainstream GIS and the related spatial database, and environmental problems are analyzed, simulated, and predicted based on a professional analysis model of various environmental elements and problems. The EIoT datastream is shown in Figure 1.

The framework of the EIoT is based on network technology, mobile communication networks, and WSN. WSN is used to sense, collect, and process environmental information; mobile communication networks are used to deliver mass environmental data to the information platform within a city; and the analysis and simulation results are published on the Internet via WebGIS and are shared by other cities. The application of network technology in the EIoT is shown in Figure 2.

GIS, map server, and environmental information server are used to carry out urban environmental analysis, simulation, and information sharing. An urban environment dynamic simulation system is used to link and upgrade the early warning system for pollution accidents and to forecast and simulate the consequences. And then, the possible influence of pollution accidents can be calculated, and the resulting information can be published to related institutions, including higher-level authorities, the public, and regions affected by pollution accidents, thereby achieving cross-regional and trans-departmental information exchange.

Figure 2. The application of network technology in EIoT.

4. Construction of the EIoT

Our EIoT was built based on the framework outlined in the previous section. The EIoT consists of data collection, data transmission, and data reception and simulation.

4.1. Data collection

Our EIoT uses wireless sensors to collect environmental data. The first step in EIoT construction was to design and make various wireless sensors for water, soil, atmosphere, noise, and wind monitoring. Each wireless sensor is fixed in one location and used to monitor the environment at, and around, that point; so in order to conduct real-time environmental monitoring over a large area, on the basis of our wireless sensors, we developed a wireless monitoring bicycle, car, boat, and plane, which provide flexible and convenient monitoring mode for water, soil, atmosphere, noise, and wind monitoring and make it possible to monitor the area where people cannot arrive easily, for example, a wireless monitoring boat can be used to monitor water quality in the center of a lake, and a wireless monitoring plane can be used to monitor atmosphere quality in the sky or survey environmental conditions of a forest.

4.2. Data transmission

The environmental data collected by sensors are transmitted to the central platform (the environmental information platform) via networks. In our EIoT, the transmission of environmental data from each node to the central platform at residential area level is via Zigbee. At the city level, the transmission of environmental data from monitoring station to the central platform is via GPRS, and at the regional and national levels, the transmission of environmental data from the central platform in a given city to the regional or national command central platform is via the Internet.

4.3. Data reception and simulation

Data reception and simulation is completed in the central platform. In our EIoT, the central platform is composed of

several servers and monitoring equipment (several television monitors and a white projection screen). Servers are used to store the environmental data from the sensors via networks and create various environmental models, and monitoring equipment is used to show in real time the monitoring and simulation results. In our EIoT, in the servers, we built databases for water quality, soil quality, atmosphere quality, noise environment, and wind environment as well as several other fundamental databases listed in the previous section. Based on these databases, we created several environmental models, for example, soil and water forecasting models which are used to forecast pollution trends, noise, and wind monitoring models for real-time monitoring and simulation, atmosphere forecasting model for real-time monitoring of atmosphere quality, and simulation of atmosphere pollution diffusion, as well as a land-use statistical model, solar energy computing model, and so on. The central platform of our EIoT is built based on WebGIS and is a network platform (<http://rcdnue.org/site.aspx>). All databases and environmental models are embedded in our central platform, and the information in the central platform is displayed on the monitoring equipment, published via the Internet and shared by the public.

4.4. Constructing the EIoT at different spatial scales

We constructed the EIoT at different spatial scales, including a typical residential area with high-density environmental sensor nodes, as well as other sample plots, and are gradually expanding it to monitor the whole city of Xiamen and eventually the whole of China. The multi-scale nature of our EIoT is shown in Figure 3.

4.4.1. Residential area level

At the residential area level, the campus of the Institute of Urban Environment (IUE), Chinese Academy of Sciences was selected as the research area. The surrounding landscape of the IUE campus is urbanizing very rapidly, making the campus a suitable area to study the impact of

Figure 3. Our EIoT at multi-spatial scales.

urbanization on the urban environment. We began monitoring water, soil, atmosphere, noise, and wind on the campus and built the command central platform (<http://rcdnue.org/site.aspx>) with the monitoring data being transmitted to the central platform via Zigbee. EIoT at this residential area level is comprehensive, has realized real-time monitoring and display, online analysis, simulation, and management and provides technical support and practical experience for the construction of the EIoT at higher levels. The detailed information is described by Su et al. (Forthcoming 2013).

4.4.2. City level

Based on the EIoT in the IUE campus, we have expanded the research area to include the whole city of Xiamen. We selected nine sample plots that can represent the environmental characteristics of Xiamen and monitor environmental factors on the sample plots. Monitoring data are transmitted to the command central platform via GPRS, based on which we can conduct real-time monitoring, show Xiamen's environmental problems, and analyze, simulate, and manage these problems online. The detailed information is described by Dong et al. (Forthcoming 2013).

4.4.3. Regional level

Pingtang is the largest island in Fujian Province and is an area where the wind environment can cause problems. We selected four sample plots which represent the wind environmental characteristics in different parts of Pingtang and monitored the wind on these sample plots. The central platform of Pingtang was built and used to save, display, and analyze the monitoring data in real time, and the central platform is linked to the command central platform at IUE via the Internet. We have also monitored environmental factors in Hongkeng (a typical 'town village' in Fujian Province described by Tang) (Tang et al. Forthcoming 2013) via wireless monitoring bicycle and car, thereby expanding the coverage and spatial scale of our EIoT at this regional area level.

4.4.4. National level

To begin EIoT construction at the national level, we first selected Ningbo in Zhejiang Province, Shangri-La in Yunnan Province, and Zili (another typical 'town village') in Guangdong Province. All of these locations are experiencing rapid urbanization or have typical urban environmental problems, and we have established environmental monitoring stations in Ningbo and Shangri-La based on EIoT in Xiamen. And, we have also monitored environmental factors in Zili via wireless monitoring bicycle and car. The EIoTs in these cities are linked up with the command central platform at IUE via the Internet and form the initial components of a national-level EIoT along with the EIoT in Xiamen, Pingtang, and Hongkeng.

5. Discussion

Following integration of diverse information about the physical world, the EIoT can be used to simulate the evolution of the urban environment by building virtual cities, which can generate results which cannot be realized by experiment or engineering. This provides a new research platform for the study of urban environment and promotes the combination of micro and macro urban environmental research, the combination of research on a single urban environment with the regional geographical environment, and the combination of temporal and spatial scales.

EIoT will broaden the study of China's urban environments, but it is a long-term project that will involve a wide range of stakeholders. A nationwide EIoT will promote environmental digitalization in China and improve scientific management of the urban environment. The digital information platform for the urban environment shared by city managers, researchers, and the public is of great significance to achieve timely feedback about environmental problems, enhance the right to know environmental information, construct a harmonious society, and build sustainable cities. It will not only strengthen urban and regional environmental protection and promote the urban-rural integration, but will also be beneficial to promote the orderly expansion of satellite towns. It could also provide a platform for the world to understand the urban environment in China.

In conclusion, our EIoT covers not only all common environmental problems but it also has great flexibility and provides space to gradually expand the amounts and types of sensors and new technologies. A functioning EIoT at the residential-area level has been completed, and an EIoT at the city and regional levels is also being accomplished. Although the national-level EIoT presently only includes a few cities and sites, the command central platform at IUE will be used to gradually expand and monitor the whole of China. The EIoT will cover the real-time monitoring of water, soil, atmosphere, noise, and wind, realize online environmental simulation and management, and provide technical support and practical experiences for urban environmental monitoring across China.

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