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The planning, construction, and management toward sustainable cities in China needs the Environmental Internet of Things

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China's rapid urbanization and its success in developing the Internet of Things (IoT) will decide its future development direction. The construction of sustainable cities is crucial to China because China has such a large population. The Xiamen Long-term Urban Ecosystem Observation and Research Station (Xiamen LUEORS) was started in 2006, together with the research related to the Environmental Internet of Things (EIoT) for Xiamen LUEORS. This paper explains the purpose, general framework, and main features of EIoT, and outlines the results of performing EIoT experiments in some areas, including a 'town village', a peculiar phenomenon of China's urbanization. It also discusses the development trends of IoT and proposes the concept of ZeroSpace Interconnection of Things (ZeroIoT, or ZeroSIT).

Keywords: Environmental Internet of Things (EIoT); urbanization; town village; ZeroSpace Interconnection of Things (ZeroIoT); digital ecological park (DEP)

Introduction

Increased migration to cities during the last 200 years, and especially the massive migration occurring during the last 100 years, has speeded up the world's urbanization process.

The world's earliest city is generally deemed to have appeared around 3500 BC, but for various reasons the early urbanization process was quite slow for a long period. The world's urban population only accounted for about 10% of the total population around 1800 and increased to about 15% by 1900. However, the year 2008 marked one of the most important stages in the human development process when, for the first time in history, more than half the world's population were living in urban areas (United Nations Population Fund 2008). As a result, the world has now entered the urban society age (Zhao et al. 2010).

Since the beginning of China's reform and opening up policy in early 1980s, cities in China have developed rapidly, resulting in an increase in the urbanization rate from 17.4% in 1978 to 51.27% in 2011 (National Bureau of Statistics of China 2012). The constant urban expansion has created a number of economic, social, urban construction and management issues, and conflicts between environmental and development interests have become increasingly conspicuous. The environmental problems experienced in developed countries during the last century have now occurred in China during the last three decades, in association with rapid economic growth. The serious present-day issues and potential future problems warn us

that the construction of sustainable cities is currently more important and urgent in China than anywhere else in the world (Zhao et al. 2011).

The rapid urbanization and related environmental problems urgently require the promotion of urban environmental science or the study of urban environment, which improves our understanding of how to integrate or couple the scientific laws of urban development and ecological processes for sustainable city construction (Zhao et al. 2008). It is generally considered that 'sustainable city' refers to urban life quality improvement in terms of ecology, culture, politics, governance, society, and economy, while leaving no burden to future generations. In short, a sustainable city is one that can provide and ensure sustainable welfare for its residents, with the capacity to maintain and improve its ecosystem services (Zhao et al. 2009). Urban ecosystem services can be generally defined as processes and conditions offered for people's survival and development by cities as social-economic-natural complex ecosystems. Welfare refers to the utility of wealth and income to humans, i.e., the extent to which human needs are met.

The research objective and contents of urban environmental science determine its complex and multidisciplinary nature, which requires more effective research methods or approaches. We believe that the Environmental Internet of Things (EIoT) will provide effective methods and important technical support both for the study of urban

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environmental science and for the planning, construction, and management of sustainable cities.

We started to build the campus of the Institute of Urban Environment (IUE), Chinese Academy of Sciences, based on the principles of digital ecological park (DEP) in 2006. A DEP is a garden-like area that is planned and designed according to ecological principles, and monitored and managed by EIoT. Simultaneously, we began to carry out research related to EIoT both for the campus, or DEP, of IUE and for Xiamen LUEORS (Long-term Urban Ecosystem Observation and Research Station). Xiamen LUEORS is mainly centered on our institute campus (Figure 1). Now a relatively sound EIoT entity and the Xiamen LUEORS with EIoT as its technical support have been put into service, and a number of associated research results have been obtained.

Idea and framework of EIoT

As an emerging and developing technology, numerous in-depth and systematic studies of IoT have been made by experts from different fields, and many definitions have been put forward from different perspectives. Our

understanding of these results is that IoT, for a specific objective, realizes the digital, smart and networked format of information acquisition, transmission, and application by integrating various kinds of possible techniques. More simply, IoT rapidly and accurately implements the process of information acquisition, transmission, and application for a specific objective.

Consequently, EIoT rapidly, accurately, and securely achieves the entire process of acquisition, transmission, and application of environmental and related information for a specific objective. According to our understanding and purpose, we established our EIoT entity to support the environment observation system, with Xiamen LUEORS as its central part, and the associated researches (Figure 2).

Due to the typical characteristics of the urban environment, our EIoT integrates both stationary and mobile sensors. Mobile sensors include both periodically and randomly operated sensors, which are installed on remote control aircraft and boats, as well as cars, bicycles, cell phones, and so on. Our EIoT also integrates geographic information system, global positioning system, and remote-sensing technologies. EIoT can be used to monitor some water,

Figure 1. The locations of Xiamen LUEORS and other monitoring sites.

Figure 2. The central platform of our EIoT to support Xiamen LUEORS.

Figure 3. The outline of our EIoT.

atmosphere, soil, sound, and wind environmental indicators to realize the collection, transportation, treatment, modeling, forecasting and early warning, and application of environmental information with online, real-time in situ and long-distance approaches (Figure 3). It also provides further scientific and technical support for the planning, construction, and management of sustainable cities.

To meet the needs of urban environment comparative analysis, we have established environmental monitoring sites in Pingtan Island and Hongkeng Village in Fujian Province, Shangri-La County in Yunnan Province, Ningbo City in Zhejiang Province, and Zili Village in Guangdong Province, among others. These monitoring sites are linked to our EIoT central platform (Figure 1). And we will continue to deploy new monitoring stations and integrate them with existing ones based upon actual need. We anticipate that in this way a nationwide EIoT could be established step by step.

Case studies based on EIoT

Through our team's efforts over a period of several years, we have made considerable progress in EIoT construction, monitoring, and research. In this issue, Wang et al. illustrate the whole framework and main contents of our EIoT (Wang et al. 2013b); Su et al. sketch the integrated monitoring and management technologies of our EIoT (Su et al. 2013); Dong et al. focus on the quadrat sampling method for urban environment network monitoring (Dong et al. 2013); Zhang et al. and Gao et al. separately elaborate their research results on water environment and wetland and soil environment mainly based on EIoT (Gao et al. 2013; Zhang et al. 2013); Chen et al. and Deng et al. separately explain their atmosphere environment studies mainly based on EIoT (Chen et al. 2013; Deng et al. 2013); Wang et al. and Zheng et al. separately introduce their sound environment and wind environment studies based on EIoT (Wang et al. 2013a; Zheng et al. 2013); Li et al. consider how to realize public participation in sustainable urban management using EIoT (Li et al. 2013); and Tang et al. show

the EIoT applications for the environmental management of town villages in China (Tang et al. 2013).

'Town villages' (村 in Chinese, or simply noted as cèn according to its Chinese pronunciation) are a phenomenon unique to China. They have emerged during China's rapid urbanization as a result of restrictions imposed by the village household registration system, land ownership and land-use regime. A cèn, or town village, is a village with considerable development of the nonagricultural economy (Zhao 2012). Registered permanent residents (whose 'Hukou' is in the village) are called farmers according to the household registration system, and their family is listed as a farmer household. As a result, they automatically possess the right to the use (but not the ownership) of an area of farmland, which is the most basic requirement for farming. However, in town villages, a considerable number of farmers do not live entirely on agricultural production, but engage in or rent out their houses and/or land for non-agricultural economic activities such as small manufacturing, agricultural byproduct processing, trading, catering, tourism, and transportation.

China's rapid urbanization has not only had a major impact on cities themselves and their surrounding areas but has also had a profound influence on the countryside, which can be seen in farmers' production processes and lifestyles, and especially in their ideas and ways of thinking. The development process of town villages is itself influencing and will continue to influence farmers' production, lives, perceptions, and thinking, while at same time often impairing the natural resources and environment of these villages. Studies of cèn are extremely important because these villages will certainly become one of the key factors determining the future development direction of the Chinese countryside, and even the country as a whole.

Discussion and prospects

Further improvement of EIoT based on the progress achieved will be necessary and will focus more on the integration of the needs of science, technology, and socio-

economic practice. The development of science and technology and the demands of practical applications are the main driving motivations to promote the development of EIoT. Therefore, during the further research and establishment of EIoT, it is important to focus on innovations and the development direction of the relevant science and technology. It is also important to focus on the practical needs of socioeconomic development, especially to predict future urban development trends.

IoT is itself advancing, and its relevant theories, methods, and technologies will be improved and developed. Along with the development of science and technology, the concept of IoT will continue to be transformed or sublimated, and its connotation, extension, and practical applications will be continuously enriched and expanded. Future representations of the Internet and IoT may be very different from their current forms, or be completely replaced by thoroughly new forms.

In fact, we can even find the germination of IoT thinking in the ancient Beacon Tower system that existed in China and other countries. In this kind of systems, fires were ignited on hills or towers to spread the news of an enemy invasion at the fastest speed possible (Djordjevic et al. 2010; Travel China Guide 2013). In other words, the Beacon Tower system could be considered as a kind of special IoT under the historic scientific and technical conditions of the time.

We envisage that the future IoT could be something like a ZeroSpace Interconnection of Things (ZeroIoT, or ZeroSIT), which will be able to realize the collection, transportation, treatment, modeling, forecasting, early warning and application of information in the shortest possible time, smallest possible space, with the smallest possible error and lowest possible insecurity. In the notion of a ZeroIoT, the zero space means that the time interval and the space interval in its whole operational process are all approaching zero, and at the same time the error and insecurity are also approaching zero. In short, the zero implies that ZeroIoT will be handy and efficacious anytime and anywhere.

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