8-2015

Massive open online networks for urban sensing: Design, deployment and challenges

Hwee Xian TAN
Singapore Management University, hxtan@smu.edu.sg

Hwee-Pink TAN
Singapore Management University, hptan@smu.edu.sg

Massive Open Online Networks for Urban Sensing: Design, Deployment and Challenges

Invited Paper

Hwee-Xian Tan
SMU-TCS iCity Lab
Singapore Management University, Singapore
hxtan@smu.edu.sg

Hwee-Pink Tan
SMU-TCS iCity Lab
Singapore Management University, Singapore
hptan@smu.edu.sg

***Abstract*—Recent escalating efforts to realize the vision of smart cities have become a global trend. Within such efforts, the setup of relevant infrastructure is necessary to enable scalable sensing and sense-making in urban environments. In this paper, we discuss the design and implementation of *MOON* - *M*assive *O*pen *O*nline *N*etworks - to interconnect large-scale and diverse IoT devices to enable the acquisition of real-time sensing data. We describe the system architecture and software protocols that form the components of *MOON*. In addition, we highlight the challenges in the deployment and management of such networks. These are derived through experiences gleaned from our extensive deployments of wireless infrastructure for large-scale, real-time sensing in both indoor and outdoor urban environments.**

I. Introduction

Efforts to realize the smart city vision is now a global phenomenon, whereby information and communications technology is harnessed to enhance the quality of lives of citizens. Such technology can be applied in various domains - such as healthcare, transport and education. With the availability of real-time sensing data provided by the integration of sensor and communications technologies, informed decision-making and appropriate response protocols can then take place among citizens, governments and other stakeholders.

*M*assive *O*pen *O*nline *N*etworks (MOON) provide the relevant infrastructure to enable large-scale, real-time sensing and sense-making of the urban environment.

1) **Massive**: A scalable infrastructure must be able to interconnect thousands of sensors and/or IoT devices. There must be inherent support for heterogeneity and interoperability of devices and network interfaces. In addition, the network should be able to support a large number of distinct application users - such as the public, government agencies, and other organizations.
2) **Open**: MOON supports the acquisition, transport, storage and retrieval of data from different sources. Both hardware and software platforms should be vendor-agnostic, to allow for sustainable innovation. An open, unified platform allows multiple user groups to re-use the same infrastructure, thereby reducing setup and operational costs. However, issues such as security, encryption and privacy have to be in place to enable seamless multi-party sharing and collaboration of resources.

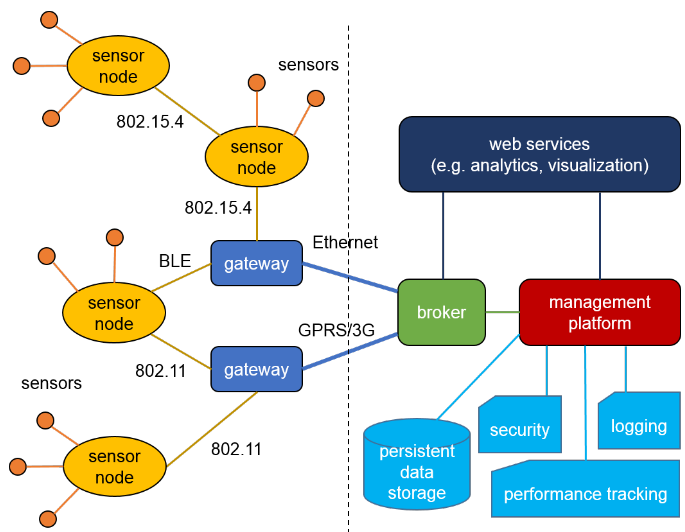

Fig. 1. Generic system architecture.

3) **Online**: With ubiquitous connectivity, data that is sensed from the urban environment can then be transported to data consumers for real-time analysis and decision-making. Online networks allow for *timely*: (i) actuation and control of devices in the system; and (ii) response protocols to be in place.

In the rest of this paper, we discuss the system architecture and design principles for MOON. We then highlight the challenges in the deployment and management of such networks, through experiences gleaned from our extensive deployments of wireless infrastructure for large-scale real-time urban sensing. Finally, we discuss a few specific applications that can make use of *massive*, *open*, *online* networks.

II. System Architecture and Design

A generic system architecture is illustrated in Figure 1. The sensor frontend comprises a tiered mesh networking platform, whereby sensor nodes are connected via single or multiple hops to one or more gateways. Each sensor node may have one or more sensing modalities - such as passive infrared (PIR), temperature, noise, humidity and dust. Each gateway is connected to the backend via backhaul communications - such as WiFi, Ethernet or cellular communications.

A. Sensor Mesh Networking Platform

Sensor-to-gateway communications is supported by multi-hop mesh networking, based on a variant of ETX [1]. Opportunistic networking allows for path diversity and resilience to intermittent link connectivity, and provides robustness for an always *online* network. Bi-directional traffic is supported for the propagation of downlink messages for control, configuration and Over-the-Air (OTA) programming. The choice of such a tiered network platform is related to practical considerations - such as scalability, power and cost of cellular communications.

To minimize energy consumption, synchronous duty cycling is used with coarse-grained time synchronization. Each sensor node periodically wakes up to transmit its own sensor data, and to forward data for other nodes. MQTT [2] - which is a lightweight, scalable and open publish/subscribe messaging transport protocol - is used for communications between the gateways and the backend components.

B. Network Management Platform

Due to the intended massive scale of the network, a management platform is required to orchestrate and manage the nodes in the network. Minimally, the management platform is responsible for: (i) security modules (such as key management and distribution, as well as data encryption and decryption to facilitate open data/infrastructure sharing); (ii) event logging for fault detection, isolation and diagnosis; (iii) services for persistent data storage; and (iv) performance tracking. Another core requirement of the platform is the support for OTA programming, to cater for extensibility of software features and remote firmware upgrades.

C. Web Services Framework

The web services framework facilitates the development and deployment of dynamic web-related services and resources - such as data calibration, data analytics and visualization - that can be used by multiple stakeholders. Through a unified Application Programming Interface (API), data can be retrieved in an efficient manner without the need for the user or developer to be exposed to the underlying database schema.

III. Deployment and Management Challenges

A. Unreliable Hardware Components

Sensor nodes may be equipped with multi-modal sensing components. The use of off-the-shelf hardware may require the physical interconnection of the hardware components via auxiliary components such as USB hubs and cables. These physical interconnections are generally not resilient to movements and high operating temperatures. Various sensing components may also require dedicated power sources.

B. Operating Environment

Nodes that are deployed in outdoor environments are subjected to harsh weather elements - such as rain and high heat. Enclosures must therefore be waterproof and well-insulated. The high operating temperatures of the outdoor environment may also lead to unpredictable behavior of the hardware. Industrial grade sensors and hardware are generally more heat tolerant, but may be several orders more expensive.

C. Intermittent Link Connectivity

The inter-nodal wireless connectivity is subject to intermittent link fluctuations, and vastly affected by various factors - such as road traffic, moving trains, human presence and rain. Deployed nodes may not be mobile or easily accessible. Inter-nodal communication techniques must therefore be robust to link intermittency and resilient to node failures. Delay tolerant networking (DTN) approaches must be undertaken to minimize data loss arising from intermittent backhaul communications.

D. Power Availability Limitations

It may not be possible for all nodes to tap onto mains power. As such, nodes may be powered by: (i) batteries with limited capacities; or (ii) various energy harvesting sources - such as solar and wind - that may have fluctuations in energy availability. Provisions must therefore be made to cater to limited and/or fluctuating energy sources, and backup power sources should be available whenever possible. Even when mains power is available for nodes, protection against power surges should be used to prevent hardware failures.

IV. Applications

We discuss specific applications that can directly benefit through the use of MOON.

1) The SHINESeniors [3] project aims to provide Smart Homes and Intelligent Neighbors to Enable Seniors and support ageing-in-place. Through the use of *open* and *always online* networks, multi-modal sensors can be installed in the homes of the elderly, to provide real-time passive monitoring of the elderly and to detect anomalies in their living patterns. This enables volunteers and caregivers to provide timely intervention through a response protocol.
2) Solar photovoltaic (PV) assets have to be intelligently maintained, for prolonged liftime, high energy throughput and low maintenance cost. Through massive and online networks of sensors to monitor PV system health, efficient management and preventive maintenance of the solar panels can then be achieved.

V. Conclusion

Many networks have been deployed for urban sensing worldwide; however, many of these deployments are small-scale, use proprietary hardware and software platforms that limit the heterogenity of the network, and may have intermittent network connectivity. Through our extensive deployment experiences, we have identified the three key criteria of sensing infrastructure for smart cities as ***massive***, ***open*** and ***online***.

References

[1] D. S. J. D. Couto, D. Aguayo, J. Bicket, and R. Morris, "A high-throughput path metric for multi-hop wireless routing," in *MobiCom*, 2003.

[2] Edited by Andrew Banks and Rahul Gupta, "MQTT Version 3.1.1. OASIS Standard. http://docs.oasis-open.org/mqtt/mqtt/v3.1.1/os/mqtt-v3.1.1-os.html," 2014.

[3] "Sensor-Enabled Homes and Personalised Care for Senior Singaporeans Living in the HDB," http://centres.smu.edu.sg/icity/shinesenior/, accessed: Jul 2015.