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EDITORIAL

IEEE ACCESS SPECIAL SECTION EDITORIAL: THE NEW ERA OF SMART CITIES: SENSORS, COMMUNICATION TECHNOLOGIES, AND APPLICATIONS

The population of cities is increasing day-by-day. According to United Nations, it is estimated that by 2050, 66% of the world's population will live in cities [item 1) of the Appendix]. This is indicative of a drive to live in more privileged and smarter environments. Therefore, there exists an increased demand for intelligent and sustainable environments that offer citizens of urban areas a high quality life. Smart cities may be a solution. Millions of dedicated and reliable sensors are required in smart cities to enhance the quality of urban living. Communications infrastructure is inevitably required for connecting these sensors. In order to better manage urban resources, there exists a need to explore issues like deployment of sensors, communications technologies, information management, and defining and deploying proper smart city applications.

Heterogeneous communication technologies are expected to play a vital role in terms of providing connectivity among different objects in smart cities. These communications technologies include wireless fidelity (WiFi) [IEEE 802.11 a/b/g/n/ac/ah/af], long term evolution (LTE) [3GPP], LTE advance (LTE-A) [3GPP], Bluetooth (IEEE 802.15.1), Zigbee (IEEE 802.15.4), and low power wide area network (LoRaWAN). Bluetooth and Zigbee are low range communications technologies and more suitable for personal area network (PAN) based applications. LoRaWAN provides low-power WANs with features specifically needed to support low-cost mobile communications. These heterogeneous communication technologies can be used in most smart city applications such as smart grid, smart metering, smart street lightening, smart health monitoring, smart transportation, waste management, and smart ambulance.

This Special Section in IEEE ACCESS is intended to provide a platform for researchers and practitioners from both academia and industry in the area of smart cities. We have invited original articles with novel contributions in sensing technologies, applications, and communication architecture, requirements and protocol design in smart cities. In this Special Section, we have included 16 high-quality articles from leading research groups around the world working on different research aspects of smart cities. Articles in this Special Section present novel ideas on smart metering, resource management, content centric network, energy and congestion-aware routing metric for energy-constraint devices, development and management of Internet of Things (IoT) based smart cities, and service oriented middleware for clouds and fog computing for smart cities.

Smart grid consists of a network that integrates communications technology with electric power infrastructure. A smart grid plays a vital role in a smart city by reforming power system, efficient energy usage, and integration of energy resources. "Smart homes" can be deemed one of the most important components of smart grids [item 2) of the Appendix]. In the work by Nadeem Javaid, *et al.* (An intelligent load management system with renewable energy integration for smart homes), demand side management model for scheduling the appliances of residential user is presented. The proposed model aims to optimize the operation time of electric appliance in smart homes, and hence, reduces the electricity bills. Smart home is widely used with household IoT. The security test of smart home is still a major problem. The work proposed by Kai Ciu, *et al.* (Automated software testing based on hierarchical state transition matrix for smart home) consists of an automatic software testing method for smart television (TV) to improve the smart TV software test efficiency. In contrast to traditional manual test methods, their proposed scheme can test more errors and also reduce test period.

Advance metering infrastructure (AMI) is another important component of smart grid and allows two-way communications between utility meters and city utility companies [item 3) of the Appendix], [item 4) of the Appendix]. An efficient routing protocol is needed for energy constraint devices of smart cities [item 5) of the Appendix], [item 6) of the Appendix]. The article by Rehmat Ullah, *et al.* (Energy and congestion-aware routing metric for smart grid AMI networks in smart city) proposed an energy and congestion-aware routing metric for smart meter networks. The proposed metric is an adaptive parent node selection scheme that considers the residue energy and queue utilization of neighbor in AMI networks. Smart metering is a basic component of smart grid in AMI. Smart metering system is an electronic system that can monitor or control electricity, gas or water consumption. It also provides more information and control than a conventional monitoring system. Correctness in reading, data recording, and real time tracking are the key advantages of smart metering. A smart meter is also capable of communicating the real time resource consumption data to central system. The work of Marina Barbiroli, *et al.* (Smart metering wireless networks at 169 MHz) presents and analyzes a cost effective network design strategy for smart metering networks in the 169 MHz frequency band. The 169 MHz frequency band is chosen because of its better performance in terms of wireless propagation, and hence, building penetration [item 7) of the Appendix]. Their solutions named as macro-cellular and lighting network layout provide a cost effective solution with already existing infrastructure.

Communications play a substantial part in providing connectivity for sensors in smart cities. Fixed relays are introduced in communications networks to increase capacity and coverage. Dimensioning, planning, optimization, and maintenance of the fixed relay can be costly. Moving relays provide more flexibility and performance gain. In the article by Xiaoxuan Tang, *et al.* (Coverage performance of joint transmission for moving relay enabled cellular networks in dense urban scenarios), the authors model and analyze coordinated multipoint with moving relays in smart cities. The authors propose a tractable model for moving relay enabled cellular networks by using stochastic geometry. The probability that a user is served with coordinated multipoint is high. Furthermore, coverage is improved when moving relay passes by macro user equipment.

Sensors are key components in smart cities. Sensor and communication modules are typically powered by batteries in most wireless sensor networks (WSNs). Therefore, designing an energy efficient algorithm is an important task to increase the network lifetime. Recently, emergence of software defined networking (SDN) enables the transformation of WSNs. SDN provides a promising solution in management of WSNs by allowing the separation of control logic from the sensor. The work by Li Peizhe, *et al.* (A game-theoretic and energy-efficient algorithm in an improved software-defined wireless sensor network) present a novel SDN-WSNs architecture to integrate SDN into WSNs. Based on their architecture, a game-theoretic energy efficient algorithms is designed to improve energy efficiency and network lifetime. One of the key challenges in WSNs is to efficiently disseminate data with minimum energy while maintaining fully-connected network topology. The work of Zeeshan Hameed Mir, *et al.* (Collaborative topology control for many-to-one communications in wireless sensor networks) presents a collaborative topology control protocol for WSNs in denser deployment scenarios. Their proposed scheme combines both dominating set based clustering and transmission power adjustment method.

Traditional methods of communication and algorithms are not scalable because IoT can cover a large area of the network. Various algorithms have been proposed for communication in the field of IoT and WSNs. They include a protocol named environment pareto dominated selection (EPDS) based on compound event barrier coverage (CEBC) by Yaoming Zhuang, *et al*. (Compound event barrier coverage algorithm based on environment Pareto dominated selection strategy in multi-constrains sensor networks), which is the first work to propose under cost, distance, time and minimum confidence constraints. For constrained application, the mutation strategy, adaptive scaling factors adaptive crossover probability strategy, and external population updating strategy are adapted to improve the coverage performance. Another communication paradigm is a content centric network (CCN) by Chan Min Park, *et al*. (Packet flooding mitigation in CCN-based wireless multimedia sensor networks for smart cities), which is robust and has features like data authenticity, in network caching, mobility, flow balance methods, and multicast data delivery. A packet diffusion-limited protocol for CCN-WSN based is also proposed for flooding of data packets and speeds up the content download.

People continue to gather to cities for several reasons, such as occupational opportunities, a better way of life, and more. As this migration continues, cities will need to become well-organized in order to keep up with the swelling population. Thus, smart cities will start to become the norm in the major municipal areas of the world. Quite simply, smart cities use IoT devices such as connected sensors, lights, and meters to collect and analyze the data. The cities then use this data to improve fractured public utilities and services. Cloud of things (CoT) is a platform that provides a platform for linking the cyber parts of a smart city with the physical part of the city. However, proper utilization of CoT and fog computing is a challenging task. In the article of Nader Mohamed, *et al*. (SmartCityWare: A service-oriented middleware for cloud and fog enabled smart city services) a service oriented middle ware "SmartCityWare" approach is proposed for effective integration of CoT and fog computing. The main purpose of SmartCityWare is to provide a virtual environment to be used to develop and deploy smart city applications. It consists of a set of services and a multi-agent runtime environment. The practicability of the proposed platform is tested with broker, invocation, and location-based services with an Arduino board for temperature and humidity measurement.

IoT is a key enabler for smart cities and offers many classic applications for smart cities. However, the implementation of IoT infrastructure at a city-scale is a challenging task. The article by Pablo Sotres, *et al*. (Practical lessons from the development and management of a smart city Internet-of-Things infrastructure: The SmartSantander testbed case) discusses the solutions to the challenges faced during the deployment and management of IoT infrastructure at city-scale which contains thousands of sensors. The deployment of IoT-based smart city infrastructure is carried out at the port city of Santander, Spain.

Due to the rising populations of cities, air pollution has turned into a severe issue for public health. Among all pollutants in the air, fine particulate matters (PM2.5) can harm a person's health. In the work by Ling-Jyh Chen, *et al*. (An open framework for participatory PM2.5 monitoring in smart cities), the authors present a participatory urban sensing framework for PM2.5 monitoring with 2500 sensing devices in Taiwan and other countries. Their proposed framework can provide micro-scale air quality information to trigger on-demand response and impelling government policymaking.

Sensing quality and network lifetime are two conflicting facet of WSNs. To extend the network lifetime, it requires keep the less active sensor nodes in networks, However, it will decrease the sensing quality. An effective solution is required to address both sensing quality and network lifetime according to the application requirement. In the article by Selina Shamin, *et al.* (Tradeoff between sensing quality and network lifetime for heterogeneous target coverage using directional sensor nodes), the authors design a framework to address the joint problem of maximizing the sensing quality and network lifetime in smart city applications.

Both increases in mobile devices and requirements of high data rate results in a spectrum scarcity problem. Spectrum scarcity problems can be dealt with by cognitive radio networks (CRNs). Energy efficiency is still an open problem in wireless communication systems. The article by Yingjiao Wang, *et al*. (Resource allocation in wireless powered cognitive radio networks based on a practical non-linear energy harvesting model) formulates the sum throughput maximization problem of secondary users in CRNs. They jointly optimize the energy harvesting time, transmit power, and sub-channel allocation. Furthermore, the article by Ekaterina Markov, *et al.* (Flexible spectrum management in a smart city within licensed shared access framework) presented an urban licensed shared access (LSA) use case. LSA enables more flexible spectrum control for future applications. An intelligent transportation system is considered with the objective to enhance safety on roads by using vehicle to everything (V2X) communication in a smart city.

A smart healthcare system is an important application in smart city. Wireless body area networks (WBAN) receive attention to automatically sense the healthcare data of a patient, and communicate to a central location for further processing. Energy efficiency requirements and quality of service (QoS) are the main issues in WBAN. In the article by Zhiqiang Liu, *et al.* (Buffer-aware resource allocation scheme with energy efficiency and QoS effectiveness in wireless body area networks), the authors designed a buffer-aware resource allocation scheme to improve energy efficiency. Their proposed scheme jointly optimizes the transmission power, the transmission rate and time slots for each sensors nodes to minimize the mix-cost of all sensors.

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APPENDIX
RELATED WORK

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