Guest Editorial Special Issue on Internet of Things (IoT): Architecture, Protocols and Services

INTERNET of Things (IoT) has been emerging as the next big thing in Internet. It is envisioned that billions of physical things or objects will be outfitted with different kinds of sensors and actuators and connected to the Internet via heterogeneous access networks enabled by technologies such as embedded sensing and actuating, radio frequency identification (RFID), wireless sensor networks, real-time and semantic web services, etc. IoT is actually cyber-physical systems or a network of networks. With the huge number of things/objects and sensors/actuators connected to the Internet, a massive and in some cases real-time data flow will be automatically produced by connected things and sensors. It is important to collect correct raw data in an efficient way; but more important is to analyze and mine the raw data to abstract more valuable information such as correlations among things and services to provide web of things or Internet of services.

This special issue features recent and emerging advances IoT architecture, protocols, services and applications. More than one hundred papers were received and peer-reviewed, out of which thirty five papers were selected for publication, which cover topics including sensors and devices for IoT, efficient communications and networking for IoT, security and privacy in IoT, crowdsensingand crowdsourcing, localization and tracking, services and applications, and IoT data modeling and management.

The first set of five papers discuss IoT sensor and device related issues. With the exponential growth of the number of devices in Internet of Things applications, the addressing strategy issues have attracted much attention. In the paper "IPv6 Addressing Strategies for IoT", Teemu Savolainen *et al.*, concentrated on presenting serious challenges towards IPv6 address allocation by examining how IPv6 can be effectively deployed for various IoT topologies particularly with emphasis on address allocation. Yuhao Wang *et al.* in the paper entitled "A Multi-bit Identification Protocol for RFID Tag Reading" presented a multi-bit identification protocol which can identify the reader's receiving sequence multi-bit by multi-bit. The protocol is designed with the low communication overheads and high identification efficiency. Honorio Martin *et al.* in their paper "Efficient ASIC Implementation and Analysis of two EPC-C1G2 RFID Authentication Protocols" have addressed implementation of Electronic Product Code (EPC) Class - 1 Generation -2 based on ASIC. They have explored the design space and provided a detailed analysis of the area occupied by the synthesized circuits, their power consumption and the throughput in terms of protocols per second. In the paper "Development of Mobile Radiation Monitoring System Utilizing Smartphone and its Field Tests in Fukushima" from Yang Ishigaki *et al.*, the authors developed low-cost but accurate mobile radiation detectors, which can be integrated with smart phones. The authors gave details about hardware design, software design, and field test results. Honggang Li *et al.* in the paper entitled "Battery-Friendly Packet Transmission Algorithms for Wireless Sensor Networks" proposed battery-aware local optimization schemes including task scheduling for different types of sensor applications in order to prolong the lifetime of battery-powered sensor nodes.

The second set includes fourteenpapers about efficient communications and networking for IoT. Luca Foschiniet *et al.* in the paper entitled "Convergence of MANET and WSN in IoT Urban Scenarios" proposed a new solution to integrate and opportunistically exploit MANET overlays for boosting urban data harvesting in IoT. The solution is validated in terms of the feasibility and effectiveness. In the paper "Wireless Sensor Networks and the Internet of Things: Optimal Estimation with Non-uniform Quantization and Bandwidth Allocation", Tao Jiang *et al.* studied the energy minimization problem for the joint estimation of a noise-corrupted parameter in WSNs. The problem is approximated as a convex optimization and thus an efficient iterative algorithm can be applied for a near-optimal solution. Yanmin Zhu *et al.* in the paper entitled "When 3G Meets VANET: 3G-Assisted Data Delivery in VANETs", investigated a sensory data gathering application of vehicular ad hoc networks (VANET). The authors are to address the hard problem of 3G-assisted data delivery in a VANET with a budget constraint of 3G traffic. An optimization problem, thus, is formed, which can be solved by integer linear programming. The conclusion is evaluated by using both synthetic vehicular traces and real vehicular 3G traces. In the article "An Experimental Study for Inter-User Interference Mitigation in Wireless Body Sensor Networks", Bin Cao *et al.* investigated and analyzed the impact of inter-user interference on packet delivery ratio and throughput. They conducted extensive experiments based on TelosB wireless body sensor network platform, considering unslotted CSMA/CA and slotted CSMA/CA modes in IEEE 802.15.4 MAC, respectively. They also proposed a light-weight hopping approach based on practical wireless body sensor network systems and investigated the performance in realistic environment. In "Scalable Channel Allocation and Access Scheduling for Wireless Internet-of-Things", Di Wu *et al.* presented "GAALS", a grid-based

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MAC protocol using Latin squares for channel allocation and access scheduling in wireless sensor networks with multiple channel communication capabilities, as an enabling technology for IoT. In GAALS, the network is organized into grids and clusters according to location information, and guarantees the network connectivity using the grid shifting algorithm. The channel access efficiency and fairness were achieved by using compact Latin square based channel access and channel allocation schedules. In the paper "Fuzzy Logic Based Multi-dimensional Link Quality Estimation for Multi-hop Wireless Sensor Networks" from Zhiqiang Guo *et al.*, the authors leveraged fuzzy logic for estimating link quality in multi-hop wireless sensor networks with collection tree protocol as the routing strategy. The proposed scheme is able to overcome the lossy and dynamic nature of wireless channels. Pradhumna L. Shrestha *et al.*. in the paper "Modeling Latency and Reliability of Hybrid Technology Networking" studied latency and reliability in multi-hop WiFi-based and ZigBee-based hybrid networks for IoT. They deduced the theoretical results of delay and reliability for such hybrid networks and found that they achieve better performance than traditional ZigBee-based sensor networks. Liang Liu *et al.* in the paper "Percolation Theory Based Exposure-Path Prevention for Wireless Sensor Networks Coverage in Internet of Things" proposed a bond-percolation theory based solution for exposure-path prevention in wireless sensor networks. They basically mapped the exposure path problem into a bond percolation model. In the paper "Quality-Driven Energy-Neutralized Power and Relay Selection for Smart Grid Wireless Multimedia Sensor Based IoTs", Runan Yao *et al.* proposed a new quality-optimized scheme for gathering multimedia information (e.g. sky camera data) in energy harvesting wireless sensor networks by jointly considering transmission power control and relay node selection strategies based on multimedia packet distortion reduction and the energy harvesting profile of each node. In the paper "Effective Data Collection via Satellite-Routed Sensor System (SRSS) to Realize Global-Scaled Internet of Things", Yuichi Kawamoto *et al.* studied effective IoT data collection via satellite systems. They proposed a divide-and-conquer approach to collect data from a large number of things based upon demand. In the paper "On Optimal Scheduling in Duty-Cycled Industrial IoT Applications using the IEEE802.15.4e MAC" from Maria Rita Palattella *et al.*, the authors studied duty-cycle scheduling issue in medium access control protocols for industrial IoT applications. Specifically, they investigated traffic-aware scheduling algorithm and compared it with conventional IEEE 802.15.4 protocol in term of energy efficiency. Dongliang Xie *et al.* analyzed the effect of multirate on the throughput and energy consumption in sensor networks and designed a new MAC protocol based on the analysis, in the paper entitled "Tradeoff between Throughput and Energy Consumption in Multirate Wireless Sensor Networks".

Security and privacy is another important aspect in IoT. Fivepapers focusing on IoT security and privacy were selected. In the article "Practical Secure Communication for Integrating Wireless Sensor Networks into the Internet of Things" by Fagen Li *et al.*, the authors proposed a heterogeneous online/offline signcryption scheme to secure communications between a sensor node and an Internet host. They proved that this scheme has the indistinguishability against adaptive chosen ciphertext attacks under the bilinear Diffie-Hellman inversion problem. It has existential unforgeability against adaptive chosen messages attacks under the q-strong Diffie-Hellman problem in the random oracle model. This method provides a new security solution for integrating wireless sensor networks into the Internet as part of the IoT. With no doubt, routing protocols determine the performance of the network directly. In the paper titled "The Impact of Rank Attack on Network Topology of Routing Protocol for Low-Power and Lossy Networks", Anhtuan Le *et al.*, studied routing protocols considering the impact of rank attack on network topology for low-power and lossy network. The rank concept here serves multiple purposes including route optimization, prevention of loops and managing control overheads. Through raising the weakness in low-power and lossy networks, their study reveals that attacks in a high forwarding load area have more impact on network performance. In the paper titled "A Lightweight Multicast Authentication Mechanism for Small Scale IoT Applications", Xuanxia Yao *et al.* proposed a lightweight scheme of multicast authentication by extending the original Nyberg's fast one-way accumulator. By evaluating the seven cardinal properties as required by multicast authentications for resource-constraint applications, the authors concluded that the proposed approach is suitable for small scale IoT applications. Xiaohui Liang *et al.* in the paper "EPS: An Efficient and Privacy-Preserving Service Searching Scheme for Smart Community" studied how to preserve privacy in service discovery and sharing for smart community. The authors proposed priority-based new schemes for Internet bandwidth sharing among different homes in the same community, which hide users' identity information and guarantees privacy accordingly. In the paper entitled "Lithe: Lightweight Secure CoAP for the Internet of Things", Shahid Raza *et al.* designed a lightweight scheme for secure constrained application protocols (CoAP) through compressing the header of datagram transport protocol security (DTLS) messages.

Crowdsensing and crowdsourcing become a new and feasible approach for sensing physical world thanks to the emerging of smart phones and other mobile devices. Panlong Yang *et al.* in the paper titled with "PassFit: Participatory Sensing and Filtering for Identifying Truthful Urban Pollution Sources" described an interesting urban sensing application for pollution monitoring. The major task in the paper is to identify the truthful pollution sources with the noisy data mitigation. The presented theoretical analysis in the paper proves that the proposed solution can achieve optimal estimation. In the paper "Sensing as a Service: Challenges, Solutions and Future Directions" introduces a new concept, Sensing as a Service (S2aaS)", Jian Tang *et al.* discussed how to provide sensing services using mobile phones via a cloud computing system. The authors identified unique challenges of designing and implementing an S2aaS cloud and comment on future research directions. In the paper "QoI-Aware Energy-Efficient Participatory Crowdsourcing" by Chi Harold Liu *et al.*, the authors proposed a new energy-efficient participatory

crowdsourcing framework with quality of information awareness using ubiquitous smart devices (e.g. phones). The proposed approach jointly considers quality of information and energy efficiency.

Four papers concentrating on tracking and localization were selected. Joe-Air Jiang *et al.* in their paper "A Distributed RSS Based Localization Using a Dynamic Circle Expanding Mechanism" has focused the importance of localization in IoT. The localization offers automatically discoverable services and knowledge relating toanobject's position. By this way, resources can be shared among devices. It is reported that the trilateration approach based on the received signal strength (RSS) is the most suitable forlocalization due to its simplicity of implementation and low hardware requirement among the various WSN techniques designedfor positioning an unknown node. In the paper "Item-Level RFID Tag Location Sensing Utilizing Reader Antenna Spatial Diversity", Shuai Shao *et al.*. have presented a robust estimation procedure for sensing the locations of passive UHF RFID tags. The system consists of a conventional UHF RFID readers, antennas and passive tags, providing additional capability to existing item-level RFID systems. The method is based on spatial deployment of the reader antennas for maximum signal diversity. The experimental results for a realistic retail scenario with multiple tagged items achieve an estimation accuracy of 35 cm. In the paper "SensTrack: Energy-Efficient Location Tracking with Smartphone Sensors" by Lei Zhang *et al.*, the authors proposed a new tracking service based on sensor hints available on the smart phone. Basically, SensTrack leverages build-in sensors (e.g. acceleration sensor and orientation sensor) to switch between GPS sampling and WiFi-based indoor location to reduce GPS usage while maintaining high tracking accuracy. Xufei Mao in the paper "iLight: Device-Free Passive Tracking Using Wireless Sensor Networks" proposed new indoor passive tracking without relying on any equipment attached to the target, but leveraging sensor networks (e.g. light sensors). The authors demonstrated the proposed scheme for tracking both single target and multiple targets in their implementation.

Three more papers about IoT data modeling and management were included in this special issue. In the paper titled "Information Abstraction for Heterogeneous Real World Internet Data" from Frieder Ganz *et al.*, the authors investigated how to improve the efficiency of data exchange betweenphysical systems (i.e. sensor devices) and cyber systems (i.e. applications). They proposed a new method to construct sensor data abstraction at local gateways, which leads to traffic load reduction in communications networks while maintaining data accuracy. Technological progress has lead the sensor network domain to an era where environmental and agricultural domain applications are completely dependent on hydrological sensor networks. However, the quality of data can vary significantly. In the paper titled "Performance Evaluation of South Esk Hydrological Sensor Web: Using Unsupervised Machine Learning and Semantic Linked Data Approach", Ritaban Dutta *et al.* proposed a Linked data approach, Unsupervised Pattern Recognition, and Semantic Ontologies based framework to assess the reliability of hydrological sensor network and evaluate the performance of the sensor network using that framework. In addition, new design framework has been used successfully to evaluate the South Esk hydrological sensor web in Tasmania. James Brusey *et al.* in the paper entitled "Edge mining the Internet of Things" explored the benefits of edge mining on the wireless, battery-powered, smart sensing devices of the Internet of Things. The proposed techniques can reduce the communication overheads, improve the energy efficiency and reduce the remote storage requirements.

At last, there were three papers which presented new IoT services and applications. In the paper "A Cyber Physical Testbed for Virtualization of RF Access Environment for Body Sensor Network", Jie He *et al.*, evaluated the performance of wireless access and localization of body sensor networks. The authors have presented a cyber physical test bed for environment virtualization to facilitate performance evaluation. A real time channel emulator has been used to emulate the wireless channel in a cybernetic way. The emulated outputs are compared with the empirical data obtained from actual measurements. An analog channel emulator for UWB technologies has been designed to overcome the bandwidth limitation of traditional digital channel emulators. In the paper "Crowd Density Estimation Using Wireless Sensor Networks", the authors presented an iterative process with two phases to address this problem. They first give a K-means algorithm to cluster various crowd density distribution in different levels based on RSSI information, after which the noises and other deviations are eliminated based on the spatial-temporal correlation of crowd distribution. They further tested the proposed strategies using 16 wireless sensor nodes and the results show that their algorithm has an accurate, efficient, and consistent performance. In the paper titled "Towards the Implementation of IoT for Environmental Condition Monitoring in Homes" from S.D.T. Kelly *et al.*, the authors implemented an IP-based home condition monitoring system using low-cost smart sensors. They studied data aggregation and other performance metrics such as system throughput and reliability.

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