# Guest Editorial Special Issue on Unmanned Aerial Vehicles Over Internet of Things

IN THE last few years, unmanned aerial vehicles (UAVs) have developed rapidly and the applications of UAVs have been expanded in wide areas, including photography, cargo delivery, inspection, and communications. Conventionally, UAVs are controlled and operated by a ground station using specific radio transmission modules, where the line-of-sight signal transmission is preferred and the operation range is limited, especially in urban areas. Using the Internet of Things (IoT) technologies, a UAV can be regarded as a terminal device connected in the ubiquitous network, where many other UAVs are communicated, navigated, controlled, and surveilled in real time and beyond line-of-sight.

The unique advantages of the UAV over IoT include: deployability at remote locations, capability of carrying flexible payloads, reprogrammability during missions, and ability to sense/measure just about anything, anywhere. However, there are also many significant research challenges that should be concerned to bring such capabilities of UAVs into practice. For example, it is expected to support low-latency control signaling, high-accuracy real-time navigation and surveillance, fast varying network topology, and high-speed media streaming. This Special Issue aims to explore the theoretical and technical research outcomes on all the aspects of UAVs over IoT.

The response to our Calls for Papers for this Special Issue was satisfactory. During the review process, each paper was assigned to and reviewed by experts in the relevant areas, with a rigorous review process. Thanks to the great support of the Editor-in-Chief of this JOURNAL, we were able to accept 21 excellent papers covering various aspects of UAVs over IoT.

In the paper "Capacity and Delay of Unmanned Aerial Vehicle Networks With Mobility," the authors study the UAV networks with multiple UAVs acting as aerial sensors, where the mobility of UAVs is exploited to construct the store-carry-and-forward transmission manner. Moreover, the capacity and delay scaling laws of UAV networks are studied, based on which a mobility control scheme is proposed to eliminate the critical range such that the capacity scaling laws of all UAVs are the same.

In the paper "A 3-D Geometry-Based Stochastic Model for UAV-MIMO Wideband Non-Stationary Channels," the authors propose a 3-D geometry-based stochastic model (GBSM) for multi-input–multi-output (MIMO) wideband nonstationary channels between the UAV and the ground user. By using a single concentric-cylinders model, they derive the expressions of the channel statistical properties of the space–time–frequency correlation function (STF-CF) and space-Doppler power spectral density (SD-PSD). Finally, the influence of some important UAV-related parameters on channel statistical properties as well as the channel nonstationary is also investigated, which may be helpful for the design of UAV communication systems.

To balance the UAV network performance and service cost, the authors of the paper "A Game Theory Approach for Joint Access Selection and Resource Allocation in UAV-Assisted IoT Communication Networks" study the joint UAV access selection and BS bandwidth allocation problems in a UAV-assisted IoT communication network. More specifically, stochastic geometry tool is used to model the position distribution of network nodes and drive the payoff expressions, such as coverage probability and ergodic rate. Based on the ergodic rate analysis, the authors propose a hierarchical Stackelberg game framework which compose of a follower evolutionary game for UAV access selection and a leader noncooperative game for BS bandwidth allocation.

Considering the challenges brought by the narrow radiation pattern of directional antennas and the mobility of UAVs in robust directional antenna-based aerial networks, a heading control strategy is presented for UAV-carried directional antennas in the paper "RSSI-Based Heading Control for Robust Long-Range Aerial Communication in UAV Networks," to establish a robust long-range aerial communication channel. Particularly, the received signal strength indicator (RSSI) is adopted as an auxiliary measuring component, and then a consensus-based unscented Kalman filtering (UKF) algorithm is developed to estimate the position of UAVs. The authors also demonstrate that the proposed method can effectively reduce the influence of malicious measurements, which significantly improve the signal strength as compared with the omnidirectional antenna-based works.

In the paper "Throughput Maximization for UAV-Enabled Wireless Powered Communication Networks," an efficient successive hover-and-fly trajectory design jointly with the downlink and uplink wireless resource allocation is studied to maximize the uplink common (minimum) throughput among all ground users over a finite UAV's flight period. After that, the authors propose a locally optimal solution by applying the techniques of alternating optimization and successive convex

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programming (SCP). Finally, it is demonstrated by simulation that the proposed UAV-enabled wireless powered communication network achieves significant throughput gains over the conventional architecture with fixed-location AP.

In the paper "Underlay Drone Cell for Temporary Events: Impact of Drone Height and Aerial Channel Environments," a communication network with an underlay aerial base station is considered to provide coverage for a temporary event. By using stochastic geometry, the authors propose a general analytical framework to compute the uplink and downlink coverage probabilities for both the aerial and the terrestrial cellular system. The proposed framework shows the nontrivial impact of the different aerial channel environments on the uplink and downlink coverage probabilities, which can be guidelines for best aerial base station deployment height.

In the paper "Privacy Protection for Internet of Drones: A Network Coding Approach," the authors develop a secure light-weight network coding pseudonym scheme to protect the privacy of cloud data in Internet of Drones (IoD). By decoupling the stored IoD cloud data from the owner's pseudonyms, it is claimed in the article that the proposed network coding-based pseudonym scheme can simultaneously defend against both outside and inside attackers.

In the paper "UAV-Aided MIMO Communications for 5G Internet of Things," the authors explore the potential gain of UAV-aided data collection in a generalized IoT scenario, where a composite channel model and rigorous energy constraints of IoT devices are carefully considered. Furthermore, a whole-trajectory-oriented optimization problem is formulated which jointly optimizes transmission duration and the transmit power of all devices. Finally, considering that practically it is difficult to predictively acquire the random small-scale channel fading prior to the UAV flight, the authors propose an iterative scheme to overcome the nonconvexity of the formulated problem.

Considering a cooperative space–air–ground three-tier heterogeneous network with UAVs, satellites, and base stations constitute, the paper "Joint UAV Hovering Altitude and Power Control for Space–Air–Ground IoT Networks" proposes a two-stage joint hovering altitude and power control solution for the resource allocation problem in UAV networks considering the inevitable cross-tier interference from space–air–ground heterogeneous networks. Specifically, the authors utilize the Lagrange dual decomposition and concave–convex procedure (CCP) method to develop a low-complexity greedy search algorithm, based on which a joint optimization of resource allocation in heterogeneous UAV networks is realized.

In the paper "Cellular Cooperative Unmanned Aerial Vehicle Networks With Sense-and-Send Protocol," the authors consider a cellular controlled UAV network in which multiple UAVs cooperatively complete each sensing task. Based on the proposed sense-and-send protocol, they formulate a joint trajectory, sensing location, and UAV scheduling optimization problem that minimizes the completion time for all the sensing tasks in the network. Then, an iterative trajectory, sensing, and scheduling optimization (ITSSO) algorithm is proposed to jointly solve the subproblems which are decoupled from the original one. The authors also provide convergence and complexity analysis of the ITSSO algorithm.

In the paper "An Efficient Wideband Spectrum Sensing Algorithm for Unmanned Aerial Vehicle Communication Networks," the authors study the application of cognitive radio technology for UAV communication networks, to provide high capacity and reliable communication with opportunistic and timely spectrum access. To overcome the weaknesses of existing compressive spectrum sensing schemes which have unnecessarily high computational complexity and low energy efficiency, an enhanced algorithm, called iterative compressive filtering, is proposed to improve the UAV network communication performance. The authors demonstrate that the proposed method achieves higher detection probability in identifying the occupied subchannels under the condition of nonstrictly sparse spectrum with large computational complexity reduction.

In the paper "Joint Routing and Scheduling for Vehicle-Assisted Multidrone Surveillance," a novel vehicle-assisted multidrone routing and scheduling problem is considered to improve the performance of vehicle-drone cooperative networks, where multiple drones sense different targets in parallel. To tackle the problem, the authors contribute an efficient vehicle-assisted multi-UAV routing and scheduling algorithm (VURA) to jointly optimizes anchor point (AP) selection, path planning, and tour assignment via nested optimization operations. Finally, performance evaluation is presented to demonstrate the effectiveness and efficiency of the proposed algorithm.

The paper "Learning to Communicate in UAV-Aided Wireless Networks: Map-Based Approaches" mainly focus on the problem of resource-constrained UAV trajectory design with optimal channel parameters learning and data throughput as key objectives, where a UAV-mounted flying base station is providing data communication services to a number of radio nodes spread over the ground. Specifically, the authors formulate and solve a learning trajectory optimization problem to minimize the estimation error of the channel model parameters, and a joint trajectory and node scheduling problem is then proposed to maximize the traffic communicated from each node to the UAV in a fair manner by using a map compression method.

In the paper "Transceiver Design and Multihop D2D for UAV IoT Coverage in Disasters," the authors mainly consider multiantenna transceiver design and multihop device-to-device (D2D) communication to guarantee the reliable transmission and extend the UAV coverage for IoT in disasters. To minimize the number of hops, the shortest-path-routing (SPR) algorithm is designed to establish D2D links for emergency networks, based on which the closed-form expressions of the number of hops and the outage probability are derived for the uplink and downlink. Due to the nonconvexity of the transceiver design problems, the authors transform them into convex ones and then propose a low-complexity algorithms to solve them efficiently.

Traditional jammer localization via multilateration is applicable for only a single jammer case. Considering the challenge to locate multiple jammers for UAV networks, the authors of the paper "Locating Multiple GPS Jammers Using Networked UAVs" propose a simultaneous localization of multiple jammers and receivers (SLMRs) algorithm by analyzing the variation in the front-end signal power recorded by the GPS receivers on-board a network of UAVs.

Moreover, they design a Gaussian mixture probability hypothesis density filter over a graph framework, which is optimized using a Levenberg–Marquardt minimizer. Finally, the authors validate the convergence and localization accuracy of SLMR algorithm through a simulated experimental setup.

In the paper "Optimizing Trajectory of Unmanned Aerial Vehicles for Efficient Data Acquisition: A Matrix Completion Approach," an optimal UAV data collection trajectory (OUDCT) scheme is proposed for improving energy efficiency and reducing redundant data by optimizing the trajectory of the UAV. The authors propose an optimal simulated annealing algorithm to plan the path of UAV based on the selected backbone sampling points. Finally, simulation results are provided to demonstrate that the OUDCT scheme can efficiently reduce data redundancy and increase the lifetime.

To explore whether the gain of UAV access points (UAPs) could be fully harvested, the paper "Performance Analysis and Optimization of UAV Integrated Terrestrial Cellular Network" investigate the performance of a downlink UAV integrated terrestrial cellular network (UTCN) and analytically study the influence of varying UAP altitude and density on the spatial throughput (ST) of UTCN. The authors reveal the limitation of the application of UAPs by showing that there exists a critical UAP density, beyond which network ST would encounter a rapid decrease. Furthermore, they tailor a probabilistic interference avoidance scheme and study the optimization of the UAP activated probability.

In the paper "UAV-Enabled Spatial Data Sampling in Large-Scale IoT Systems Using Denoising Autoencoder Neural Network," the authors propose a UAV-enabled spatial data sampling scheme using denoising autoencoder (DAE) neural network to relieve the data rate of trunk link for data uploading while ensure data accuracy. More specifically, a UAV-enabled edge-cloud collaborative IoT system architecture is developed, based on which DAE neural network is selected as the fundamental data sampling and reconstruction model. The authors also develop a novel bounded-size $K$-means clustering algorithm for cluster formation and the cluster-based spatial data sampling in the proposed scheme, and predetermine the lower and upper bounds of cluster size as well.

In the paper "A Satisficing Conflict Resolution Approach for Multiple UAVs," the authors are concerned with exploring the theoretical and technical research outcomes for the conflict resolution of multiple UAVs. For example, they formulate the conflict resolution problem as a game model and design strategies of changing both the heading and the velocity based on flight characteristics of UAVs. Furthermore, required time of arrival (RTA) is developed to ensure that the whole system can reach a socially acceptable compromise.

The paper "Joint Offloading and Trajectory Design for UAV-Enabled Mobile Edge Computing Systems" addresses a UAV-aided mobile edge computing (MEC) system, where a number of ground users are served by a moving UAV equipped with computing resources. To minimize the sum of the maximum delay among all the users in each time slot, the authors propose a novel penalty dual decomposition (PDD)-based algorithm to jointly optimize the UAV trajectory, the ratio of offloading tasks, and the user scheduling variables with several constraints, such as the energy consumption and UAV trajectory. Besides, they also extend the algorithm to minimize the average delay.

In the paper "UAV-Aided Projection-Based Compressive Data Gathering in Wireless Sensor Networks," the authors propose the utilization of UAVs to collect data in dense wireless sensor networks (WSNs) using projection-based compressive data gathering (CDG) as a novel solution methodology. More specifically, a joint optimization problem is formulated to optimize node clustering, forwarding tree construction and CH selection per cluster, and UAV trajectory planning for energy-efficient data collection in dense WSNs. The problem is divided into four complementary subproblems and close-to-optimal results are generated with lower complexity.

To conclude, we would like to appreciate all the authors for their support and excellent contributions. We also would like thank all the Reviewers for their efforts in reviewing the papers, and for their valuable comments and constructive suggestions for improving the quality of the papers. Finally, we appreciate the advice and support of the Editor-in-Chief of this JOURNAL, Dr. Xuemin (Sherman) Shen, for his help in the whole publication process. We hope the papers in this Special Issue would be good references to the future research in UAVs over IoT networks.

LIN BAI, *Guest Editor*
School of Cyber Science and Technology
Beihang University
Bejing 100191, China

ISMAIL GUVENC, *Guest Editor*
Department of Electrical and Computer Engineering
North Carolina State University
Raleigh, NC 27695 USA

QUAN YU, *Guest Editor*
Peng Cheng Laboratory
Shenzhen 518055, China

WEI ZHANG, *Guest Editor*
School of Electrical Engineering and Telecommunications
University of New South Wales
Sydney, NSW 2052, Australia

**Lin Bai** (SM'17) received the Ph.D. degree from Swansea University, Swansea, U.K., in 2010.

In 2011, he joined Beihang University, Beijing, China, as an Associate Professor, where he is currently Assistant Dean with the School of Cyber Science and Technology. His current research interests include signal processing of wireless communications and UAV communications.

Dr. Bai serves as an Editor for IEEE WIRELESS COMMUNICATIONS LETTERS and the *Journal of Communications and Information Networks*.

**Ismail Guvenc** (SM'10) has been an Associate Professor with North Carolina State University, Raleigh, NC, USA, since 2016. He has authored or co-authored over 200 conference/journal papers, several standardization contributions, 3 books, and over 30 U.S. patents. His current research interests include 5G wireless networks, UAV communications, and heterogeneous networks.

Mr. Guvenc was a recipient of the 2015 NSF CAREER Award, the 2014 Ralph E. Powe Junior Faculty Award, and the 2006 USF Outstanding Dissertation Award.

**Quan Yu** (SM'15) received the Ph.D. degree in fiber optics from the University of Limoges, Limoges, France, in 1992.

In 1992, he joined the faculty of the Institute of China Electronic System Engineering Corporation, Beijing, China. He is currently the Principal Research Scientist with the Peng Cheng Laboratory, Shenzhen, China. His current research interests include architecture of wireless networks, optimization of protocols, and cognitive radios.

Dr. Yu is an Academician of the Chinese Academy of Engineering and the Founding Editor-in-Chief of the *Journal of Communications and Information Networks*.

**Wei Zhang** (F'15) received the Ph.D. degree from the Chinese University of Hong Kong, Hong Kong, in 2005.

He is a Professor with the University of New South Wales, Sydney, NSW, Australia. His current research interests include 5G communications, mmwave communications, and space information networks.

Dr. Zhang is the Editor-in-Chief of IEEE WIRELESS COMMUNICATIONS LETTERS and the *Journal of Communications and Information Networks*. He is a member of the Board of Governors of the IEEE Communications Society.