

Digital Object Identifier 10.1109/ACCESS.2021.3077816

: EDITORIAL

IEEE ACCESS SPECIAL SECTION EDITORIAL: FLYING AD HOC NETWORKS: CHALLENGES, POTENTIALS, FUTURE APPLICATIONS, AND WAY FORWARD

The theory and operations of data dissemination in wireless scenarios have endless applications based on the characteristics of underlying networks. The wireless networks that do not rely on any pre-existing infrastructure such as wireless sensor networks (WSNs), wireless mesh networks (WMNs), wireless body area networks (WBANs), or Mobile *Ad hoc* Networks have gained much attention due to their smart applications. Such types of wireless networks are categorized under wireless *ad hoc* networks with no central administration. With the rapid development in the applications of such types of *ad hoc* networks, Flying *Ad hoc* networks, commonly known as unmanned aerial vehicles (UAVs), have recently captured the attention of vendors and investors due to the flying nature of the entities. The UAV is officially called drone, which has the ability to fly without a human pilot aboard. The network of drones or UAVs has commercially gained popularity because of its applications such as surveillance, agriculture, and photography. For instance, the new applications that are being developed for Flying Ad hoc Network (FANET) bring up new challenges such as multipath propagations, severe shadowing, traffic load balancing, mobility, congestion, and high error rates, which usually result in degradation of the network. On the contrary, the applications developed and enabled in FANET may also result in collision with commercial flights due to the highlighted challenges.

Commercial flight companies have reported to the Federal Aviation Administration (FAA) about the tremendous increase of more than 50% in unmanned vehicles in 2019. However, such an increase in UAVs results in an increase in the network traffic of FANET that may lead to an unbalanced traffic distribution and collision. In order to cope with such kinds of challenges, the network traffic of the aforementioned network must be distributed to such a degree that it should neither disturb the commercial flights nor any UAV in the network.

This Special Section has provided a platform for researcher and practitioners from both academia and industry in the area of FANETs.

We published one invited article from highly reputed researchers working in the area of FANETs. The invited article, authored by Dapper e Silva *et al.*, “STFANET:

SDN-Based Topology Management for Flying Ad Hoc Network,” addresses the orientation of UAVs and their management using software-defined network (SDN) for FANET. The main objective is to provide a communication link among independent nodes in the network by establishing and maintaining a FANET topology. Simulation results carried out for the military settings show the efficiency of the proposed protocol by achieving 25% of packet loss in the data plane, 1.5 ms of latency, and 71% of connectivity on average in a dynamic scenario.

Nine other high-quality articles have been included in this Special Section from leading researchers and their research groups around the world working on state-of-the-art and revolutionary research aspects of FANET and its applications.

The first contribution, authored by Sharma *et al.*, is “Secure and Reliable Resource Allocation and Caching in Aerial-Terrestrial Cloud Networks (ATCNs),” which addresses the issues of efficient resource allocation and content-caching in a highly dynamic network environment as employed in FANET type networks like ATCNs. For this purpose, the resources in such types of network have been allocated reliably and securely using cog-chain protocol by establishing a virtual communication mechanism between the nodes and the content caching servers. The cog-chain provides an easy way of implementation to provide secure authentication with authorization with lightweight facilities. The proposed cog-chain protocol is validated through consequential gains by means of signaling overheads, computational time, and reliability. It is suggested in the article that cog-chain can be applied to several integrated and hierarchical networks to resolve several issues related to security and integrity to allocate the resources in a secure and reliable manner.

The next article entitled “BICSF: Bio-Inspired Clustering Scheme for FANETs,” by Khan *et al.*, proposes a scheme for energy aware cluster formation and cluster head election on the basis of Glowworm Swarm Optimization (GSO) algorithm. In addition, the authors have proposed an efficient cluster management algorithm using behavioral study of Krill Herd (KH). The performance of BICSF is evaluated, and the results show that the proposed BICSF outperforms other clus-

tering algorithms with bio-inspired features with reference to energy consumption, delivery success ratio, cluster building time, and lifetime.

In the article entitled “The Broadcast Storm Problem in FANETs and the Dynamic Neighborhood-Based Algorithm as a Countermeasure,” by Pires *et al.*, the authors discuss the broadcast storm that is generated while maintaining the UAVs coordination by allowing all the nodes in the network to continuously forward the required messages, so that each node in the network knows the condition of the network in order to proceed with the transmission of message through wireless medium in a contention-based environment. In addition, they have proposed an innovative Dynamic Neighborhood-Based (DNB-BSP) algorithm. The proposed algorithm was evaluated through computer simulations and was validated based on outdoor experiments. The results reveal that the proposed mechanism as compared to flooding scenario reduces the duplicate messages in the network by more than 98% and message delivery ratio by more than 95%.

In the article “Exploiting Dual Connectivity for Handover Management in Heterogeneous Aeronautical Network,” by Wang *et al.*, the authors address the problem of handover management and its overhead using stochastic optimization with queue backlog. In addition, they proposed a mechanism to schedule the traffic with dual connectivity in heterogeneous aeronautical network to provide handover management. Furthermore, they tried to transform stochastic optimization problem to deterministic using the Lyapunov optimization theory. Afterward, they proposed optimal and feasible strategies. It has been concluded that the handover overhead would be minimal if the baseline strategy is utilized instead of the conventional optimal strategy.

In the article “Adaptive Hello Interval in FANET Routing Protocols for Green UAVs,” by Mahmud and Cho, the authors highlight the issue of exchanging 1-hop hello messages. These messages are exchanged with the neighbors in a periodic manner, after a defined interval. However, this may increase the message overhead and energy consumption. Considering this problem, they have proposed a mechanism to determine hello intervals based on mission environment parameters in real-time scenarios and attributes, such as with the UAV speed, transmission range, number of UAVs deployed in the network, and the volume of the allowed airspace. The analysis performed through the simulation has shown that the proposed mechanism has saved an average of 25% energy compared to AODV and 23% compared to OLSR.

The next article “Robust RFID based 6-DoF Localization for Unmanned Aerial Vehicles,” by Zhang *et al.*, proposes an enhanced UAV system with a Radio-Frequency Identification (RFID) to investigate UAVs for indoor applications without using the Global Positioning System (GPS) service in order to precisely and accurately localize a UAV. In addition, the authors proposed an algorithm using Bayesian filter to track the RFID tags, through the position of the tags using phase measurements of the RFID tag responses in a global

coordinate system, which is referred to as radio-frequency UAV (RFUAV). The performance of the proposed work has been tested in an indoor environment. The system is capable of measuring 2.5 degree orientation error and 0.04 m position error.

The article “A Traffic-Aware Approach for Enabling Unmanned Aerial Vehicles (UAVs) in Smart City Scenarios,” by El-Sayed *et al.*, addresses the problem of high computation capabilities and latency in smart cities with fixed infrastructure to support efficient vehicular applications. The authors proposed a solution called SWIM that uses network edges as mobile RSUs in situations and areas where fixed infrastructure is not feasible to deploy because of cost and time constraints. Additionally, the authors use such networks in an urban area and apply them where severe traffic is generated temporarily. This traffic may create congestion; therefore, they have designed a strategy that can relocate the edges as per the need with respect to the condition of the traffic and the congestion behavior.

Another article titled “Channel Measurement and Resource Allocation Scheme for Dual-Band Airborne Access Networks,” by Zhang *et al.*, highlights objectives such as wide coverage, long continuous work, and high throughput for ground users. The constraints have been applied with limited power supply, frequency reuse, and large propagation distance. The authors have proposed a hybrid-spectrum scheme for aerial base stations (ABS) on the airship. Additionally, the ABS employed multiple bands to provide continuous connectivity for ground users. These bands are UHF and S bands. The results showed that the airship network performance has been significantly improved by using the proposed mechanism.

In the last article entitled “Joint Resource Allocation and Trajectory Control for UAV-Enabled Vehicular Communications,” by Deng *et al.*, the authors discuss vehicular communications based on unmanned-aerial-vehicles to highlight the problem of resource allocation. In this work, UAV is used to act as a temporary cellular base station. A 3-partite graph matching algorithm is used to enhance the channel conditions and mobility of UAV in disaster situations in order to restore vehicular communication. The article concluded that the proposed algorithm only achieves a maximum weighted matching for 3-partite graph instead of achieving the optimal solution.

In conclusion, we are thankful to all the researchers who submitted their original articles to our Special Section. Along with this, we are also extremely appreciative of the contributions and time spent by the reviewers in providing their constructive comments, recommendations, and suggestions. Furthermore, we also would like to acknowledge the cooperation of the IEEE ACCESS editorial staff members and the guidance from the Editor-in-Chief. Moreover, we hope that this Special Section on Flying *Ad hoc* Networks: Challenges, Potentials, Future Applications, and Way Forward will contribute to the knowledge base and will benefit the research community at large.

OMER CHUGHTAI, Lead Editor

Department of Electrical and Computer Engineering
COMSATS University Islamabad, Wah Campus
Wah Cantt 47040, Pakistan

SIDI-MOHAMMED SENOUCI, Guest Editor

DRIVE EA1859
University of Bourgogne Franche Comté
F58000 Nevers, France

MUBASHIR HUSAIN REHMANI, Guest Editor

Department of Computer Science
Munster Technological University (MTU)
Cork, T12 P928 Ireland

SOUMAYA CHERKAOUI, Guest Editor

Department of Electrical and Computer Engineering
Université de Sherbrooke
Sherbrooke, QC J1K 2R1, Canada

LEILA MUSAVIAN, Guest Editor

School of Computer Science and Electronics Engineering
University of Essex
Colchester CO4 3SQ, U.K.

SHIWEN MAO, Guest Editor

Department of Electrical and Computer Engineering
Auburn University
Auburn, AL 36849, USA



OMER CHUGHTAI received the B.Eng. degree from the University of Engineering and Technology (UET), Taxila, Pakistan, in 2006, the M.S. degree in computer engineering from COMSATS University Islamabad, Pakistan, in 2010, and the Ph.D. degree from Universiti Teknologi PETRONAS, Malaysia, in 2016. He worked as a Research Engineer on a sponsored research and development project titled “End-to-End mobility management framework (EMF) for multi-homed mobile devices.” He is currently working as an Assistant Professor with the Department of Electrical and Computer Engineering, COMSATS University Islamabad, Wah Cantonment, Pakistan. He has several national and international research publications. His research interests include cross-layer protocol design, routing in low-power wireless *ad hoc* networks, smart grid, traffic load balancing and management, energy harvesting, energy efficiency, mobile multimedia communications, the Internet of Things, self-organized networks, and artificial intelligence. He received an Internet Engineering Task Force (IETF) Fellowship to participate at the 91st IETF Meeting, Honolulu, HI, USA, from the Internet Society (ISOC).

He is currently an Associate Editor of IEEE ACCESS.



MUBASHIR HUSAIN REHMANI (Senior Member, IEEE) received the B.Eng. degree in computer systems engineering from the Mehran University of Engineering and Technology, Jamshoro, Pakistan, in 2004, the M.S. degree from the University of Paris XI, Paris, France, in 2008, and the Ph.D. degree from the University Pierre and Marie Curie, Paris, in 2011. He worked as Postdoctoral Researcher with the Telecommunications Software and Systems Group (TSSG), Waterford Institute of Technology (WIT), Waterford, Ireland. He also served for five years as an Assistant Professor with the COMSATS Institute of Information Technology, Wah Cantonment, Pakistan. He is currently working as an Assistant Lecturer with the Department of Computer Science, Cork Institute of Technology, Ireland. He has authored/edited total eight books, two books with Springer, two books published by IGI Global, USA, three books published by CRC Press–Taylor and Francis Group, U.K., and one book with Wiley, U.K. He received the Best Researcher of the Year 2015 of COMSATS Wah Award in 2015, the certificate of appreciation Exemplary Editor of the IEEE COMMUNICATIONS SURVEYS AND TUTORIALS for

the year 2015 from the IEEE Communications Society, the Best Paper Award from IEEE ComSoc Technical Committee on Communications Systems Integration and Modeling (CSIM), in IEEE ICC 2017, and the Best Paper Award from the Higher Education Commission (HEC), Government of Pakistan, in 2017. He was a recipient of the Best Paper Award from *Journal of Network and Computer Applications* (Elsevier), in 2018. He consecutively received a Research Productivity Award, in 2016 and 2017, and ranked #1 in all Engineering disciplines from Pakistan Council for Science and Technology (PCST), Government of Pakistan. He has been selected for inclusion on the annual Highly Cited Researchers 2020 list from Clarivate. His performance in this context features in the top 1% in the field of computer science. The highly anticipated annual list identifies researchers who demonstrated significant influence in their chosen field, or fields, through the publication of multiple highly cited articles during the last decade. Their names are drawn from the publications that rank in the top 1% by citations for field and publication

year in the Web of Science citation index. From 2015 to 2017, he served as an Associate Editor for IEEE COMMUNICATIONS SURVEYS AND TUTORIALS. He is serving as a Column Editor for book reviews in *IEEE Communications Magazine*. He is appointed as an Associate Editor of IEEE TRANSACTIONS ON GREEN COMMUNICATION AND NETWORKING. He currently serves as an Associate Editor for *IEEE Communications Magazine*, *Journal of Network and Computer Applications (JNCA)* (Elsevier), and the *Journal of Communications and Networks (JCN)* and a Guest Editor for *Ad Hoc Networks* journal (Elsevier), *Future Generation Computer Systems* journal (Elsevier), the IEEE TRANSACTIONS ON INDUSTRIAL INFORMATICS, and *Pervasive and Mobile Computing* journal (Elsevier). He is currently an Area Editor of the IEEE COMMUNICATIONS SURVEYS AND TUTORIALS.



LEILA MUSAVIAN received the Ph.D. degree in telecommunications from the Centre for Telecommunications Research (CTR), Kings College London, U.K. She was a Lecturer at InfoLab21, Lancaster University, from December 2012 to August 2016, a Senior Lecturer at InfoLab21, Lancaster University, from August 2016 to November 2016, a Research Associate at McGill University, from 2011 to 2012, a Research Associate at Loughborough University, U.K., from 2009 to 2010, and a Postdoctoral Fellow at INRS-EMT, Canada, from 2006 to 2008. She was a Deputy Pro-Vice-Chancellor of research at the University of Essex, from September 2018 to December 2020 and a Reader in telecommunications at the School of Computer Science and Electronic Engineering, from December 2016 to October 2020. She is currently working as a Professor of wireless communications at the University of Essex. Her research interests include radio resource management for 6G/B5G communications, low latency communications, machine learning for communications, mmWave communications, massive MIMO, and energy harvesting communications.

She was an Executive Editor of *Transactions on Emerging Telecommunications Technologies*, from 2016 to 2019, and an Associate Editor of *Internet Technology Letters* (Wiley). She was an Editor of IEEE TRANSACTIONS ON WIRELESS COMMUNICATIONS from 2015 to 2020. She has been a Lead Chair of UHS5G WP in IEEE Globecom 2018, UHSLLS WP in IEEE WCNC 2019, and URLLC Special Session in IEEE PIMRC 2018, a TPC Co-Chair of CorNer 2016 (in conjunction with ISWCS 2016), a Co-Chair of mmWave 5G (STEMCOM 2016), and a TPC member of several conferences, including IEEE ICC, IEEE GLOBECOM, IEEE WCNC, IEEE ICCCN, IEEE PIMRC, and ChinaCom. She was the Workshop Co-Chair of VTC-Spring-2020. She is currently the Wireless Communications Symposium Lead Co-Chair of IEEE ICC 2021, Montreal, Canada, and a TPC Chair of IEEE CANMAD 2021, Portugal.



SIDI-MOHAMMED SENOUCI (Member, IEEE) received the Ph.D. degree in computer science from the University of Pierre-et-Marie-Curie, in October 2003, and the HDR degree from INP Toulouse, France. From December 2004 to August 2010, he was a Researcher with the France Telecom Research and Development (Orange Labs) Lannion. Since September 2010, he has been a Professor with ISAT, a major French Post-Graduate School, Nevers, France, and part of the University of Bourgogne. He participated or still participates in several national and European-wide research projects. Among them, FP7 FOTsis, ITEA CarCoDe, ITEA FUSE-IT, and FUI PARFAIT. He holds seven international patents on these topics and published his work in major IEEE conferences and renowned journals. He is a member of the Communications Society and an Expert Senior of the French Society of Electricity and Electronics (SEE). He also acted or still acts as a TPC Member of different IFIP, ACM, or IEEE conferences and workshops. He was the Chair of IEEE ComSoc IIN Technical Committee, TCIIN, from 2014 to 2016, and a Co-Chair of VehiCom2009, IEEE Globecom2010, IEEE WCMC2010, IEEE Globecom 2011, IEEE ICC'2012, and IEEE ICC'2017. He serves as a Guest Editor for premium journals, such as *Ad hoc* journal, *IEEE Network Magazine*, *IEEE ACCESS*, *IEEE Vehicular Technology Magazine*, *IEEE AHSN TC Newsletter*, and the French journal *REE*.



SOU MAYA CHERKA OUI (Senior Member, IEEE) joined as a Faculty Member with the Université de Sherbrooke, Canada, in 1999. She is currently a Full Professor with the Department of Electrical and Computer Engineering, Université de Sherbrooke. Since 2005, she has been the Director of INTERLAB, a research group that conducts research funded both by government and industry. Before joining the Université de Sherbrooke, she worked for industry as a Project Leader on projects targeted at the Aerospace Industry. She has held invited positions at leading institutions, including the University of California at Berkeley, Bell Laboratories, Monash University, and the University of Toronto, and an adjunct position at Lulea University, Sweden. In particular, she works on next generation networks (5G and beyond), edge computing/network intelligence, and communication networks for verticals, such as connected and autonomous vehicles, the IoT, and Industrial IoT. She has published over 200 research articles in reputed journals and conferences. She avails of a long research experience in wireless networking. Her work resulted in technology transfer to companies and to patented technology. She co-edited

seven books and collective works. Her research and teaching interest includes wireless networks. Her work was awarded with recognitions and best paper awards, including the Best Paper Award from the IEEE Communications Society Flagship Conference IEEE ICC, in 2017. She has chaired prestigious conferences, such as IEEE LCN 2019. She has served as a Symposium Co-Chair for flagship conferences, including IEEE ICC 2021, IEEE ICC 2018, IEEE Globecom 2018, IEEE Globecom 2015, IEEE ICC 2014, and IEEE PIMRC 2011. She has also served as an Industrial Track Chair for IEEE ICC 2021. She has been an Associate Editor and a Guest Editor of several IEEE, Wiley, and Elsevier journals. She is currently a Senior Editor of the IEEE JOURNAL ON SELECTED AREAS IN COMMUNICATIONS, an Associate Editor of IEEE NETWORK and *Vehicular Communications* (Elsevier), and a Guest Editor of IEEE ACCESS. She is a Professional Engineer in Canada. She has been serving as the Chair of the IEEE Communications Society IoT-Ad hoc and Sensor Networks Technical Committee, from 2020 to 2021. She was also named a Distinguished Lecturer from the IEEE Communication Society.



SHIWEN MAO (Fellow, IEEE) received the Ph.D. degree in electrical and computer engineering from Polytechnic University, Brooklyn, NY, USA. He is currently a Professor and Earle C. Williams Eminent Scholar Chair with the Department of Electrical and Computer Engineering, and the Director of the Wireless Engineering Research and Education Center (WEREC), Auburn University, Auburn, AL, USA. His research interests include wireless networks, multimedia communications, and smart grid. He received the IEEE ComSoc TC-CSR Distinguished Technical Achievement Award, in 2019, and the NSF CAREER Award, in 2010. He was a co-recipient of the 2021 IEEE Communications Society Outstanding Paper Award, the IEEE Vehicular Technology Society 2020 Jack Neubauer Memorial Award, the IEEE ComSoc MMTC 2018 Best Conference Paper Award, the IEEE ComSoc MMTC 2017 Best Conference Paper Award, the Best Demo Award from IEEE SECON 2017, the Best Paper Awards from IEEE GLOBECOM 2015, 2016, and 2019, IEEE WCNC 2015, IEEE ICC 2013, and the 2004 IEEE Communications Society Leonard G. Abraham Prize in the

Field of Communications Systems. He is on the Editorial Boards of IEEE TRANSACTIONS ON COGNITIVE COMMUNICATIONS AND NETWORKING, IEEE TRANSACTIONS ON WIRELESS COMMUNICATIONS, IEEE TRANSACTIONS ON NETWORK SCIENCE AND ENGINEERING, IEEE TRANSACTIONS ON MOBILE COMPUTING, IEEE INTERNET OF THINGS JOURNAL, *IEEE Multimedia*, IEEE NETWORKING LETTERS, *IEEE Network*, *ACM GetMobile*, and *KeAi Digital Communications and Networks*, among others. He is also the TPC Co-Chair of IEEE INFOCOM 2018 and a TPC Vice Chair of IEEE GLOBECOM 2022.

...