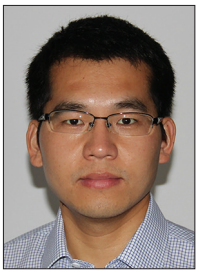
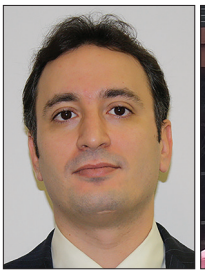
MULTI-CHANNEL COGNITIVE RADIO AD HOC NETWORKS


Haitao Zhao


Nurul I. Sarkar


Jalel Ben-Othman


Oliver Holland


Amine Maaref


Wei Tan

Cognitive radio ad hoc networks (CRAHNs) are equipped with the intrinsic capabilities of cognition and self-organization, providing a flexible spectrum-aware communication paradigm in wireless networks. Since available spectrum mostly manifests as several discontinuous frequency ranges, CRAHNs should be able to operate on multiple frequency channels. Multi-channel CRAHNs can alleviate interference and improve the spectrum utilization with greater flexibility for channel access. The promising applications of multi-channel CRAHNs include large-scale machine-to-machine (M2M) communication, the Internet of Things (IoTs), high-density Wi-Fi, and unmanned aerial vehicle (UAV) swarms.

Multi-channel CRAHNs impose unique challenges due to the distributed dynamic network topology and the temporal or spatial variations in spectrum availability. To overcome these challenges, fundamental problems in multi-channel CRAHNs have to be carefully resolved with respect to spectrum sensing, convention resolution, network topology maintenance, and application support. Accordingly, we have seven articles carefully selected from a large number of quality submissions in this Feature Topic.

The first article, "Compressed Wideband Spectrum Sensing: Concept, Challenges and Enablers" by Bechir Hamdaoui *et al.*, gives a tutorial on compressed wideband spectrum sensing. It present insights describing how comprehensive sampling has been leveraged to allow the recovery of spectrum occupancy information in wideband spectrum access. The article describes new techniques that exploit occupancy heterogeneity in wideband access to enhance spectrum sensing recovery efficiency, and then presents cooperative approaches that exploit machine learning to improve spectrum sensing even further. The compressed sensing-based approach is important for future communications systems in order to achieve good performance with less complexity. The new ideas presented in this article can help researchers get insight into wideband spectrum sensing research and development.

The second article, "Treating Cooperative Spectrum Sensing as Image Segmentation: A New Data Fusion Scheme" by Keyu Wu *et al.*, also contributes to the realm of spectrum sensing techniques. It proposes a new cooperative spectrum sensing algorithm, which is inspired by image segmentation tasks in computer vision. The algorithm is able to identify transmission opportunities in the face of spatially heterogeneous spectrum and Byzantine attacks, which are two of the main sensing challenges in CRAHNs.

The third article, "Contention Resolution Mechanisms for Multi-Channel Cognitive Radio Ad Hoc Networks" by Yi-Tang Wang *et al.*, provides an overview on channel hopping (CH) rendezvous protocols, which is receiving much attention lately to make distributed terminals meet on the same unoccupied channel. It presents contention resolution mechanisms in the CH rendezvous protocol. Specifically, the multi-round contention resolution approach is compared to the single-round version. We believe that the work presented in this article will help readers to develop a deeper understanding of CH sequence design, contention resolution, concurrent transmissions, and spectral efficiency in practical CRAHNs.

The fourth article, "Clustering in Multi-Channel Cognitive Radio Ad Hoc and Sensor Networks" by Mustafa Ozger *et al.*, presents the motivations and challenges of node clustering in CRAHNs. Node clustering is an efficient topology management technique to regulate communication and allocate spectrum resources in CRAHNs. This article thoroughly investigates the benefits of node clustering in topology control, spectrum management, and energy saving. It also provides a brief overview on existing clustering schemes.

The fifth article, "Channel Clustering Based QoS Level Identification Scheme for Multi-Interface Multi-Channel Ad Hoc Cognitive Radio Networks" by Amjad Ali *et al.*, focuses on the problem of channel clustering rather than node clustering. It proposes a novel Bayesian non-parametric channel clustering scheme. The proposed scheme exploits usage features of the primary user and models them with an infinite Gaussian mixture model and collapsed Gibbs sampling method to identify an appropriate cluster of licensed channels that can fulfill stringent QoS requirements of secondary users. The performance of the proposed scheme is validated using real data traces under different traffic conditions. The unsupervised learning nature of the proposed scheme makes it more practical for real-life scenarios.

The sixth article, "Constructing a Robust Topology for Reliable Communications in Multi-Channel Cognitive Radio

Ad Hoc Networks" by Yan Shi *et al.*, presents inspiring work on constructing a distributed *k*-channel-connected and conflict-free topology in a multi-channel CRAHN. The merit of the proposed scheme lies in guaranteeing the connectivity of a CRAHN when $k - 1$ licensed channels are reclaimed simultaneously and without knowledge of affected cognitive users, which is found to be a formidable hurdle in current *k*-edge and *k*-vertex connectivity solutions. This work is helpful to ensure more reliable communications among secondary users.

The seventh article, "Emotion-Aware Cognitive System in Multi-Channel Cognitive Radio Ad Hoc Networks" by Xiping Hu *et al.*, presents an interesting application of CRAHNs called the emotion-aware cognitive system. Multidimensional emotional data collection and processing approaches are described that can facilitate the deployment of various emotion-aware mobile applications in multi-channel CRAHNs. It highlights the implementation and orchestration of several key technologies adopted in the study for different emotion-aware mobile applications.

We thank the contributors who submitted manuscripts for this Feature Topic, as well as the reviewers who have provided helpful reviews. We thank Dr. Osman Gebizlioglu and Dr. Tarek El-Bawab, past and current Editors-in-Chief, for their kind encouragement, guidance, and valuable comments throughout the process of putting together this Feature Topic. We also thank the IEEE publication staff, particularly Ms. Peggy Kang, for their assistance in preparing the Feature Topic for publication. We hope that the articles in this feature topic will stimulate the readers of *IEEE Communications Magazine* to actively work in this interesting area of research.

BIOGRAPHIES

HAITAO ZHAO [SM] (haitaozhao@nudt.edu.cn) holds a Ph.D. from the National University of Defense Technology (NUDT), China, and is currently the deputy director of the Cognitive Communication Department at NUDT. His main research interests include cognitive radio networks and self-organized networks, where he has published over 100 refereed articles. He has served as a TPC member of IEEE ICC '14–17, GLOBECOM '16 and '17. He was the Guest Editor for several Special Issues of prestigious journals on cognitive radio networks.

NURUL I. SARKAR [SM] (nurul.sarkar@aut.ac.nz) holds a Ph.D. from the University of Auckland and is currently an associate professor and leader of the Network and Security Research Group at the Auckland University of Technology, New Zealand. He is a regularly invited keynote speaker, Chair, and Committee member for various national and international fora. He has published over 160 refereed articles and served on the Editorial Review Boards of several prestigious journals.

JALEL BEN-OTHMAN [M](jalel.ben-othman@univ-paris13.fr) is currently a full professor at the University of Paris 13. His research interests are in the areas of wireless ad hoc and sensor networks, VANETs, IoT, and performance evaluation and security in wireless networks in general. He is currently on the Steering Committee of *IEEE TMC*, an Editorial Board member of several journals (*IEEE Network*, *COMML*, *JCN*, *IJCS*, etc.). He has also served as TPC Co-Chair for IEEE GLOBECOM and ICC.

OLIVER HOLLAND [M] (oliver.holland@kcl.ac.uk) is a senior researcher at King's College London, working on spectrum sharing technologies among others. He has an established record in spectrum-related standards activities, including leadership of various standards, and has undertaken project, academic, event, and other leadership roles, within IEEE and elsewhere. He has achieved various accolades for his work, most recently creating and leading a team/submission/idea that won the 0.5 m EUR European Union Collaborative Spectrum Sharing Prize.

AMINE MAAREF [SM] received his Ph.D. degree in telecommunications from INRS-EMT, University of Québec, in 2007. He is an LTE and NR technical expert with Huawei Technologies in Ottawa, Ontario, Canada, focusing on 5G radio access design. He has been a Guest Editor for several Special Issues of IEEE journals and magazines, and currently serves as an Editor of *IEEE Transactions on Wireless Communications* and a founding Managing Editor of *IEEE 5G Tech Focus*.

WEI TAN (twtanwei@gmail.com) received his Ph.D. degree from the Department of Automation, Tsinghua University, China. He is currently a research staff member at IBM T. J. Watson Research Center. From 2008 to 2010 he was a researcher at the Computation Institute, University of Chicago and Argonne National Laboratory. His research interests include large-scale machine learning, GPU, and distributed computing.