COOPERATIVE AND COGNITIVE PARADIGMS FOR GREEN HETNETS


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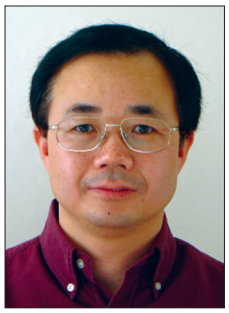
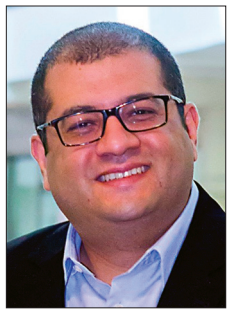

LIE-LIANG YANG


XIANBIN WANG


KWANG-CHENG CHEN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The vision of wireless 2020 is to become a smart, sustainable and inclusive economy, and as part of these priorities the world have set forth the 20:20:20 targets where greenhouse gas emissions should be reduced by 20 percent, whilst energy from renewable source efficiency should be increased by that respective amount. In fact, in today s energy conscious society, Information and Communication Technology (ICT) account for 2 percent of global CO2 emissions. To place this in perspective, a medium sized cellular network uses as much as 170,000 homes. Therefore, new solutions are required whereby operators can accommodate this additional traffic volume whilst reducing their investments in new infrastructure and beyond that significantly reducing their energy bill.

Green Terminals for the future network have the aim to avoid falling victim to the energy trap of 4G mobile systems in HetNets by investigating and demonstrating energy saving technologies for multi-standard wireless mobile devices, exploiting the combination of cognitive radio and cooperative strategies while still maintaining the required performance in terms of data rate and QoS to support active applications. The joint application of these two technologies in HetNets has led towards new paradigms in network design and deployment for energy saving, providing a stepping stone towards economic and environmental sustainability for the future. This notion is further extended by investigating lightweight security approaches, which are a pivotal requirement when the wireless link goes beyond the trusted circle of users and involves a foreign proxy device that requires new ways of managing confidentiality, integrity and authentication. This special issue of IEEE Wireless Communications puts together some recent results in the area of cooperation and cognitive communication for Green HetNets. This theme reflected in the very large number of papers we have received for this issue. 30 papers were submitted to this issue, out of which we have selected top 8 research articles.

In the first article, "Energy Efficiency in Heterogeneous Wireless Access Networks" by Shobanraj Navarantnarajah *et al.*, the authors bring forward the important aspect of energy savings in wireless access networks. The authors specifically focus on the energy saving opportunities in the recently evolving heterogeneous networks (HetNets), both single-RAT and Multi-RAT. Issues such as sleep/wakeup cycles and interference management are discussed for co-channel Single-RAT HetNets. In addition to that, a simulation based study for LTE macro-femto HetNets is presented, indicating the need for dynamic energy efficient resource management schemes. Multi-RAT HetNets also come with challenges such as network integration, combined resource management and network selection. Along with a discussion on these challenges, the authors also investigate the performance of the conventional WLAN-first network selection mechanism in terms of energy efficiency (EE) and suggest that EE can be improved by the application of intelligent call admission control policies.

In the second article, "Cognitive Antenna Selection Relay for Green Heterogeneous Healthcare Networks" by Stephen Wang *et al.*, the authors presents the latest progress on green healthcare research in HetNet, where devices are capable of switching between multiple radio access technologies (RAT) and each RAT operates on a different frequency channel. After outlining the design features and challenges of a medical service paradigm for green cognitive medical body area networks (MBAN), measurements are made to investigate the turn-on characteristics of a power amplifier (PA) in terms of excess energy consumption and turn-on delay. The authors then present a multi-mode PA architecture for an MBAN relay system. An energy-efficient PA switch/stay mechanism is also presented. This allows the proposed PA architecture to operate given a transmission outage probability and transmission delay constraint. Antenna selection between two heterogeneous RATs is exploited to improve the transmission reliability. Both measurement and numerical results are provided to corrob-

orate the performance of the proposed architecture and its switch/stay mechanism.

In the third article, "Lean and Mean: Network Coding for Commercial Devices" by Achuthan Paramanathan *et al.*, the authors presents the real-life measurements of energy savings gains of two design styles of network coding, namely, inter- and intra-session network coding using commercial platforms, including Open-Mesh routers and various mobile phones. The authors demonstrate that the energy per bit invested in coding/decoding operations can be several orders of magnitude smaller than that used for transmission/reception, while also maintaining processing speeds as high as several hundreds of Mb/s or even several Gb/s depending on the device and coding configuration used.

In the fourth article, "Exploiting 4G Mobile User Cooperation for Energy Conservation: Challenges and Opportunities" by Bechir Hamdaoui *et al.*, the authors focuses on exploiting user cooperation as a way of conserving energy in 4G mobile networks. The authors first begin by overviewing user cooperation and illustrating its potential for reducing energy consumption. Then, the authors describe the key challenges 4G mobile users face vis-a-vis of cooperation. Finally, the authors discuss some of the techniques proposed in literature to address these challenges by highlighting their methodologies, advantages, and disadvantages.

In the fifth article, "Energy-Aware Cooperative Networks: Enabling Technologies, Operation Design, and Benchmarking" by Najah Abu Ali, the author discusses the enabling technologies for energy-aware Cooperative Communication Networks (CCNs), the challenges behind employing these technologies and the open research issues. The author also discusses the lack of benchmarking EE metrics and a performance evaluation framework. The author also proposes an EE scheme for a heterogeneous WiFi-sensor network to address these issues.

In the sixth article, "Effect of Realistic Channel Conditions on the Energy Efficiency of Network Coding-aided Cooperative MAC Protocols, Operation Design, and Benchmarking" by Angelos Antonopoulos *et al.*, the authors focus on the impact of correlated long-term slow fading (shadowing) on the performance of distributed wireless systems. As a case study, the authors discuss in detail the performance of a cooperative NC-aided Automatic Repeat reQuest (ARQ) MAC protocol under correlated shadowing conditions. The authors results reveal interesting trade-offs between throughput and energy efficiency, highlighting the importance of considering the slow fading effect in the design of cooperative MAC protocols.

In the seventh article, "Coalition Formation Game Towards Green Mobile Terminals in Heterogeneous Wireless Networks" by Firooz Saghezchi *et al.*, the authors present the innovative approach which motivates Mobiel Terminals (MTs) to cooperate, while addressing the issue of isolating selfish players. MTs assess radio channels and disseminate the acquired information as well as their available resources to sketch a global view of the radio environment. Based on this view, coalitions are formed whenever energy saving is foreseeable. Within a coalition, MTs pool their resources and perform their tasks cooperatively to maximize their energy efficiency. Simulation results validate that the proposed approach can effectively double the battery lifetimes of MTs, while successfully eliminating selfish players from cooperative groups.

In the last article, "Predictive Green Wireless Access: Exploiting Mobility and Application Information" by Hatem Abou-zeid *et al.*, the authors investigate the potential of utilizing predictions of user location and application information as a means to energy saving. The authors discuss the development of a predictive green wireless access (PreGWA) framework and identify its key functional entities and their interaction. To demonstrate the potential energy savings the authors then provide a case study on buffered video streaming and illustrate how exploiting predictions can minimize BS resource consumption within a single cell, and across a network of cells. Finally, to emphasize the practical potential of PreGWA, the authors present a distributed heuristic that reduces resource consumption significantly without requiring considerable predictions or signaling overhead.

The articles included in this Special Issue consider different aspects of Cooperative and Cognitive Paradigms for Green HetNets which will be very significant in the context of the evolving LTE-Advanced (and beyond) networks. We hope that you enjoy reading this issue and find the articles useful. We would like to thank all the authors for submitting their work and the reviewers for their time in reviewing the articles. Thanks to EUREKA CELTIC Green-T, Marie Curie GREENET and FCT SMARTVISION projects whose idea conceived us to organize this Special Issue. We acknowledge the support from Professor Hsiao Hwa Chen who has guided us in this endeavor and Jennifer Porcello for her editorial support.

BIOGRAPHIES

SHAHID MUMTAZ [M] (smumtaz@av.it.pt) is currently working as Senior Researcher and Technical Manager at Institute of Telecommunication Aveiro, Portugal under 4Tell group. Prior to his current position, he worked as Research Intern at Ericsson Research Labs in 2005 at Karlskrona, Sweden. From March 2002 till August 2002, he was working as System Engineer at Pakistan Telecommunication (PTCL). He received his M.Sc. and Ph.D. degrees in Electrical & Electronic Engineering from Blekinge Institute of Technology (BTH) Karlskrona, Sweden and University of Aveiro, Portugal in 2006 and 2011, respectively. HIsShahid M.Sc. and Ph.D. is funded by Swedish government and FCT Portugal.He has been involved in several EC R&D Projects (CoDIV, FUTON, C2POWER, GREENET, GREEN-T ORCALE, ROMEO, FP6, FP7) in the field of green communication and next generation wireless systems. In EC project, he holds the position of technical manager, where he oversees the project from a scientific and technical side, managing all details of each work packages which gives the maximum impact of the project's results for further development of commercial solutions. He has been also involved in two Portuguese funded project (SmartVision & Mobilia) in the area of networking coding and development of system level simulator for 5G wireless system. His research interests lie in the field of architectural enhancements to 3GPP networks (i.e., LTE-A, user plan & control plan protocol stack, NAS and EPC), green communications, cognitive radio, cooperative networking, radio resource management, cross-layer design, heterogeneous networks, M2M and D2D communication, and baseband digital signal processing. He has more than 45 publications in international conferences, journal papers and book chapters. He is also editor of the two books and a guest editor for special issue in *IEEE Wireless Communications Magazine* and *IEEE Communication Magazine*. He has been on the technical program committee of different IEEE conferences, including Globecom, ICC, and VTC, and chaired some of their symposia. He was the workshop chair of IEEE ISWCS,13 in Germany and recipient of the 2006 IITA Scholarship, South Korea.

LIE-LIANG YANG [M'98, SM'02] received his B.Eng. degree in communications engineering from Shanghai TieDao University, Shanghai, China in 1988, and his MEng and Ph.D. degrees in communications and electronics from Northern (Beijing) Jiaotong University, Beijing, China in 1991 and 1997, respectively. From June 1997 to December 1997 he was a visiting scientist of the Institute of Radio Engineering and Electronics, Academy of Sciences of the Czech Republic. Since December 1997, he has been with the University of Southampton, United Kingdom, where he is the professor of wireless com-

munications in the School of Electronics and Computer Science. His research has covered a wide range of topics in wireless communications, networking and signal processing. He has published over 290 research papers in journals and conference proceedings, authored/co-authored three books and also published several book chapters. The details about his publications can be found at http://www-mobile.ecs.soton.ac.uk/lly/. He is a fellow of the IET, served as an associate editor to the *IEEE Trans. on Vehicular Technology* and *Journal of Communications and Networks (JCN)*, and is currently an associate editor to the *IEEE Access and the Security and Communication Networks (SCN) Journal*.

XIANBIN WANG [S'98, M'99, SM'06] is an Associate Professor at The University of Western Ontario and Canada Research Chair in Wireless Communications. He received his Ph.D. degree in electrical and computer engineering from National University of Singapore in 2001. Prior to joining Western, he was with Communications Research Centre Canada as Research Scientist/Senior Research Scientist between July 2002 and Dec. 2007. From Jan. 2001 to July 2002, he was a system designer at STMicroelectronics, where he was responsible for system design for DSL and Gigabit Ethernet chipsets. He was with Institute for Infocomm Research, Singapore (formerly known as Centre for Wireless Communications), as a Senior R & D engineer in 2000. His primary research area is wireless communications and related applications, including adaptive communications, wireless security, and wireless infrastructure based position location. He has over 150 peer-reviewed journal and conference papers on various communication system design issues, in addition to 23 granted and pending patents and several standard contributions. He is an IEEE Distinguished Lecturer. He was the recipient of three IEEE Best Paper Awards. He currently serves as an Associate Editor for *IEEE Wireless Communications Letters*, *IEEE Transactions on Vehicular Technology* and *IEEE Transactions on Broadcasting*. He was also an editor for IEEE Transactions on Wireless Communications between 2007 and 2011. He was involved in a number of IEEE conferences including GLOBECOM, ICC, WCNC, VTC, and ICME, in different roles such as symposium chair, track chair, TPC and session chair

KWANG-CHENG CHEN received B.S. from the National Taiwan University in 1983, M.S. and Ph.D. from the University of Maryland, College Park, United States, in 1987 and 1989, all in electrical engineering. From 1987 to 1998, he worked with SSE, COMSAT, IBM Thomas J. Watson Research Center, and National Tsing Hua University, in mobile communications. Since 1998, He has been a Professor at Graduate Institute of Communication Engineering and Department of Electrical Engineering, National Taiwan University, Taipei, Taiwan, ROC. He was appointed as the Irving T. Ho Chair Professor from 2007 to 2008. Since 2009, he is the Director of the Graduate Institute of Communication Engineering, and Director of Communication Research Center. He was visiting Hewlett-Packard Laboratories in California USA during 1997 and a Guest Professor at the Delft University of Technology, Netherlands, 1998, Aalborg University, Denmark, 2008. He was adjunctly appointed by the Executive Yuan Science and Technology Advisory Group to plan Taiwan's communication and networking technologies during 1998–2002, including telecommunication deregulation, cellular/fixed-network licensing, and facilitation of NCC under the authorization of Premiere. He was elected as an IEEE Fellow in 2007 Class, one of Ten Outstanding Young Engineers in 1994, one of Ten Outstanding Young Persons (the most prestigious achievement award for people under age 40 in Taiwan) in 1996, NSC Excellent Research Award in 2000, Outstanding Engineering Professor in 2002, and listed in the 15th edition Marquis Who's Who in the World in 1998 and Who's Who in Industry in 1999, and was the IEEE Communication Society Asia Pacific Board Director during 2002-2003. He was invited as a speaker in the United Nation ITU TELCOM 95 Technology Summit and Asia TELCOM 97 Strategy Summit. He also led APEC Telecommunication Working Group WTO Implementation task group. He co-authored IEEE papers to receive 2001 ISI Classic Citation Award, IEEE ICC 2010 Best Paper Award, 2010 IEEE GLOBECOM GOLD Best Paper Award, and received 2011 IEEE ComSocWireless Communication Recognition Award. His research interests include wireless communications and network science.

ABD-ELHAMID M. TAHA's [SM] main research focus is radio resource management in wireless networks, which is concerned with the allocation of the wireless resource at both the call and the scheduling level. Recent themes in this direction include resource schedulers with reduced complexity, and enabling machine-to-machine communications. Other currently active areas of interest include simplified localization in massive wireless sensor networks, mobile security in the Internet of Things and modelling in networked cyber-physical systems. This latter aspect refers to facilitating the analysis of networks with both computing and physical components, such as vehicles, robots, and unmanned flight. His broad expertise in wireless and mobile networks has been demonstrated through extensive publications and lectures, in addition to a co-authored book on broadband wireless networks such as LTE and LTE-Advanced.