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# ADVANCES IN COOPERATIVE AND RELAY COMMUNICATIONS

Traditionally, relays have been used to extend the range of wireless communication systems. However, in recent years, many exciting applications of relay communications have emerged. One such emerging application is to assist in the communication between the source and destination terminals via some cooperation protocol. By controlling medium access between source and relay terminals, coupled with the appropriate modulation or coding in such cooperative schemes, it has been found that the diversity of the communication system can be improved. In multi-user systems, different users can also act as cooperative partners or relays to share resources and assist each other in information transmission, thereby creating a cooperative network. One other emerging application is the exchange of information between multiple users through relay(s). In such cases, by exploiting the knowledge of one's own transmitted signal, the throughput of these systems can be drastically increased.

For cooperative and relay communications, the medium access control (MAC) layer also has many unique features. The MAC in this case is concerned with more than one-hop communication, is distributed and cooperative, and works for multipoint-to-multipoint communication. The MAC also needs to have knowledge about network topology and account for node mobility. Accordingly, new MAC layer designs must be devised to include new functionalities as well as MAC layer routing. With the large benefits to be reaped from employing cooperative and relay techniques, several standardization groups, such as IEEE 802.16 and IEEE 802.11, have started standardization processes to include such technologies in their prevailing standards.

With interest from both the research and industrial communities gaining momentum, there is an urgent need to better understand as well as keep track of cutting edge research in cooperative and relay communications. We have planned this feature topic to help address that need, as well as to help researchers looking to jump on the bandwagon. Therefore, we focus on recent advances, but also include survey articles on cooperative and relay communications.

The response to our Call for Papers on this feature topic of *IEEE Communications Magazine* was overwhelming, with over 50 articles submitted. All the papers were reviewed by experts in the relevant area, with at least three independent reviews for each paper and a rigorous two-round review process. Due to the lack of space, we can only accommodate six excellent articles covering various aspects of cooperative and relay communications involving physical layer (PHY), MAC, network layer, and cross-layer modeling and design.

The first article, "Distributed Transmit Beamforming: Challenges and Recent Progress" by R. Mudumbai *et al.*, reviews promising recent results in architectures, algorithms, and working prototypes on distributed transmit beamforming, and the challenges that must be surmounted. Directions are also discussed for future research needed to translate the potential of distributed beamforming to practice.

In the second article, "Cooperative Relay to Improve Diversity in Cognitive Radio Networks," Q. Zhang *et al.* give a brief overview about the interplay of cooperation and cognitive radio technologies, propose a relay-assisted D-OFDM for data transmission as the fundamental component for the whole system, and also present a new MAC protocol in a Universal Software Radio Peripheral (USRP)-based testbed.

The third article, "Link Layer Diversity and Above in Multihop Wireless Networks" by Y. P. Chen *et al.*, summarizes the causes of channel diversity in wireless communications and how it is perceived at different layers of multihop wireless networks. They concentrate on link layer diversity, and discuss the challenges and possible diversity schemes at the network layer.

H. Shan *et al.* analyze the issues and challenges in designing an efficient MAC scheme for multihop wireless ad hoc networks in the fourth article, "Distributed Cooperative MAC for Multi-hop Wireless Networks." They propose a cross-layer cooperative MAC protocol that is backward compatible with 802.11 networks, and can adapt to the channel condition and payload length.

In the fifth article in this topic, "Cooperative Network Implementation Using Open Source Platforms," T. Korakis *et al.* describe two programmable cooperative communica-

tion testbeds built at the Polytechnic Institute of NYU to demonstrate that cooperative techniques indeed work in practice.

Last but not least, J. J. Garcia-Luna-Aceves *et al.* present in the sixth and final article, "Context Aware Protocol Engines for Ad Hoc Networks," an example of context-aware packet switching in MANETs known as CAPE. CAPE is based on nodes storing the entire context within packets to be switched, and each data packet consists of only its payload and a pointer to bind it to the stored context.

In closing, we would like to thank all the authors for their excellent contributions. We also thank the reviewers for their dedicated time in reviewing the papers, and providing valuable comments and suggestions for refining the quality of the articles. We appreciate the advice and support of former and current Editors-in-Chief of *IEEE Communications Magazine* Drs. Thomas Chen and Nim K. Cheung, and Sue Lange and Joseph Milizzo for their help in the publication process.

## BIOGRAPHIES

WOON HAU CHIN (w.h.chin@ieee.org) received B.Eng. and M.Eng. degrees in electrical engineering from the National University of Singapore in 1999 and 2000, respectively, and a Ph.D. degree in electrical engineering from Imperial College London, United Kingdom, in 2004. From 2000 to 2008 he was with the Institute for Infocomm Research, Singapore, where he was involved in the standardization of IEEE 802.11n and 3GPP LTE. He was also involved in several industrial projects on wireless LANs and Beyond 3G systems. He was concurrently an adjunct assistant professor at the National University of Singapore from 2005 to 2008. Since the end of 2008 he has been with Toshiba's Telecommunications Research Laboratory, Bristol, United Kingdom. He has held positions on several conference organizing committees, and is on the technical program committees of numerous international conferences. He was also TPC co-chair of the International Symposium on Wireless Pervasive Computing 2008 and a TPC co-chair of the Transmission Technologies track at the IEEE Vehicular Technology Conference 2008 Spring. He was the founding chair of the Vehicular Technology Chapter in Singapore, and held that position from 2006 to 2008.

YI QIAN [M'95, SM'07] received a Ph.D. degree in electrical engineering with a concentration in telecommunication networks from Clemson University, South Carolina. He is with the National Institute of Standards and Technology, Gaithersburg, Maryland. His current research interests include information assurance, network security, network management, network design, network modeling, simulation, and performance analysis for next-generation wireless networks, wireless sensor networks, broadband satellite networks, optical networks, high-speed networks, and the Internet. He has publications and patents in all these areas. He was an assistant professor in the Department of Electrical and Computer Engineering, University of Puerto Rico at Mayaguez (UPRM) between July 2003 and July 2007. At UPRM he taught courses on wireless networks, network design, network management, and network performance analysis. His research and curriculum development efforts were funded by, among others, National Science Foundation, General Motor, IBM, and PRIDCO, with more than $2 million in total award amount during his four years at UPRM. Prior to joining UPRM in July 2003, he worked for several startup companies and consulting firms in the areas of voice over IP, fiber optical switching, Internet packet video, network optimization, and network planning as a technical advisor and senior consultant. He also worked several years for the Wireless Systems Engineering Department, Nortel Networks, Richardson, Texas, as a senior member of scientific staff and technical advisor. While at Nortel, he was a project leader for various wireless and satellite network product design projects, customer consulting projects, and advanced technology research projects. He was also in charge of a wireless standard development and evaluation project in Nortel. He is a member of ACM.

GIOVANNI GIAMBENE [M'97] received a Dr.Ing. degree in electronics in 1993 and a Ph.D. degree in telecommunications and informatics in 1997, both from the University of Florence, Italy. From 1994 to 1997 he was with the Electronic Engineering Department of the University of Florence. He was Technical External Secretary of the European Community COST 227 Action (Integrated Space/Terrestrial Mobile Networks). He also contributed to the SAINT Project (Satellite Integration in the Future Mobile Network, RACE 2117). From 1997 to 1998 he was with OTE of the Marconi Group, Florence, Italy, where he was involved in a GSM development program. In the same period he also contributed to the COST 252 Action (Evolution of Satellite Personal Communications from Second to Future Generation Systems) research activities by studying PRMA protocols for voice and data transmissions in low earth orbit mobile satellite systems. In 1999 he joined the Information Engineering Department of the University of Siena, Italy, first as a research associate and then as an assistant professor. He teaches the advanced course in telecommunication networks at the University of Siena. From 1999 to 2003 he participated in the project Multimedialità, financed by the Italian National Research Council (CNR). From 2000 to 2003, he contributed to the Personalized Access to Local Information and Services for Tourists (PALIO) IST Project within the EU FP5 program. He was also Vice-Chair of the COST 290 Action (www.cost290.org) for its entire duration, 2004–2008, entitled Traffic and QoS Management in Wireless Multimedia Networks (Wi-QoST). At present, he is involved in the SatNEx network of excellence of the FP6 program in the satellite field, as work package leader of two groups on radio access techniques and cross-layer air interface design (http://www.satnex.org). He also participates in the FP7 Coordination Action Road Mapping Technology for Enhancing Security to Protect Medical and Genetic Data (RADICAL) as work package leader (http://www.radicalhealth.eu/). He has published the following books: as author, *Queuing Theory and Telecommunications: Networks and Applications* (Springer, May 2005); and as Editor, *Resource Management in Satellite Networks: Optimization and Cross-Layer Design* (Springer, April 2007).