POWER LINE COMMUNICATIONS FOR AUTOMATION NETWORKS AND SMART GRID

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Power line communications (PLC) reuses power lines for communication purposes. It is an "old" technology whose commercial use for voice communication and control goes back to the beginning of the last century (see the excellent History Column article by Mischa Schwartz [1]). Since then, PLC applications have always been with us. But PLC technology has only gained attention in the broader public with the advent of broadband PLC for Internet access and in-home multimedia applications in the late 1990s. For example, *IEEE Communications Magazine* published the two Feature Topic issues, "Power Line Local Area Networking" [2] and "Broadband Is Power: Internet Access through the Power Line Network" [3], in 2003. Recently, the focus of the PLC community has widened and, in fact, shifted back to areas innate to PLC: PLC for control and automation systems. The PLC technology enabling such systems often operates at frequencies below 500 kHz, and it is referred to as narrowband PLC. One impetus for this development has been the need for a powerful communication infrastructure that enables the idea of smart grid. Power utilities have been native users of PLC technology, and it is expected that PLC will play a role in the blend of technologies composing the smart grid communication infrastructure. The PLC research community, which has always benefitted from strong participation of engineers from industry, has responded to the renewed interest in PLC solutions for automation networks, including smart grid. This can be seen from the many keynotes, panels, and technical contributions on this topic at (power line) communications conferences, most notably the IEEE International Symposium on PLC (ISPLC) and the Workshop on PLC organized by members of and supported by the IEEE Communications Society Technical Committee on PLC (TC-PLC). Within the IEEE Communications Society (IEEE ComSoc), due to the opportunities of PLC for smart grid, the TC-PLC plays a prominent role in recent IEEE ComSoc smart grid activities. Furthermore, in 2010, not one but two major standardization efforts for narrowband PLC were launched: IEEE P1901.2, "Standard for Low Frequency Narrow Band Power Line Communications for Smart Grid Applications" (sponsored by IEEE ComSoc), and ITU-T G.9955/56, "Narrow-band OFDM power line communication transceivers." The broad objective of the two groups is to define advanced PLC technology in the frequency bands below 500 kHz to support smart grid applications. Interestingly, design choices popular in modern wireless communications systems, in particular the use of multicarrier modulation at the physical layer, will also play a dominant role in narrowband PLC. Multicarrier modulation has already been adopted in the recently approved IEEE 1901 for broadband PLC and ITU-T G.9960 for broadband PLC, coax, and twisted pair standards using frequency bands from 1.8 to 250 MHz. This is not a coincidence, but evidence of the fact that PLC inherits several characteristics from wireless communications, such as multipath propagation, shared medium, and the broadcast nature of the channel.

In the Call for Papers for this Feature Topic issue we solicited contributions on "new advances and directions for PLC in generic automation networks and in networks to enable the smart grid concept." While, as the title of the Feature Topic issue suggests, specific attention is given to PLC networks for smart grid, we did not wish to limit the scope to such networks. There are many interesting applications outside of smart grid, such as PLC for automation in industry environments, PLC for lighting automation systems, and PLC for in-vehicle communication networks, which were in the research and application domain long before the term smart grid became popular. Nevertheless, the great majority of the manuscript submissions considered PLC for smart grid, including the four manuscripts accepted for this Feature Topic issue.

The four articles in this Feature Topic issue cover a broad range of aspects of PLC for automation networks and smart grid. The first article, "Channel Characterization and System Verification for Narrowband Power Line Communications in Smart Grid Application," deals with the properties and emulation of the transmission channel for PLC. The authors focus on PLC in the so-called CENELEC A band (9–95 kHz) using underground cables in the low-voltage distribution grid. They present channel measurements, a channel model that incorporates the main features of the power line channel, and finally a programmable hardware-based emulator for PLC system design and evaluation. The second article, "G.hnem: The New ITU-T Standard on Narrowband PLC Technology," presents an update on the narrowband PLC standardization work items G.9955 and G.9956 in the Telecommunication Standardization Sector of the International Telecommunication Union (ITU-T), collectively referred to as G.hnem. The authors provide a brief introduction to narrowband PLC and existing noninteroperable solutions, by which the efforts on G.hnem standardization are motivated. This is followed by an overview of the

network architecture, physical layer, and data link layer of the prospective standard, which the authors expect to be approved in December 2011. The essentially parallel effort sponsored by IEEE ComSoc in the IEEE P1901.2 Working Group is also briefly mentioned. While we did not receive a submission about P1901.2 for this Feature Topic issue, we hope that members of this Working Group present the technical specifications of the PLC technology considered in P1901.2 to the readers of this magazine in another issue in the near future. The next article, "An IP-Centric High-Rate Narrowband PLC System for Smart Grid Applications," describes a PLC platform for communication in the low-voltage and medium-voltage distribution domain based on the IPv6 protocol, providing future-proof integration of PLC into utility networks. The presented architecture to support IP over PLC is a result of ongoing research in the project Distribution Line Carrier: Verification, Integration and Test of PLC Technologies and IP Communication for Utilities (DLC+VIT4IP) funded under the 7th Framework Programme by the European Commission. The final article in this Feature Topic issue, "PLC Concept for LVDC Distribution Systems," demonstrates the feasibility of PLC for communication over low-voltage direct current (LVDC) systems, which have been receiving a great deal of attention from electricity providers. The authors describe PLC channel characteristics based on a test setup, from which system design criteria, in particular signal coupling strategies, are derived. Different from the other three articles, broadband PLC is considered as an appropriate PLC solution. Data rates on the order of several megabits per second are demonstrated theoretically and through practical transmission tests.

We believe that this selection of articles contains valuable new and overview information for professionals working in the PLC area, and also provides an interesting read for the generally knowledgeable engineer and manager who wants to learn about the possibilities, challenges, and solutions for PLC. In this context, we would also like to point the reader to the three Book Reviews in this issue of *IEEE Communications Magazine*, discussing three recent publications dedicated to PLC technology, and the "Best Readings in Power Line Communications" collection [4].

We would like to thank all authors who submitted manuscripts to this Feature Topic issue and the reviewers for their help in selecting the four articles published here. We much appreciate the excellent support we received from Editor-in-Chief, Dr. Steve Gorshe, and we gratefully acknowledge the help of the publication staff, in particular Joseph Milizzo and Jennifer Porcello.

REFERENCES

[1] M. Schwartz, "Carrier-Wave Telephony Over Power Lines: Early History," *IEEE Commun. Mag.*, vol. 47, no. 1, Jan. 2009, pp. 14–18.
[2] H. A. Latchman and L. W. Yonge, Guest Eds., "Power Line Local Area Networking," *IEEE Commun. Mag.*, vol. 31, no. 4, Apr. 2003.
[3] S. Galli, A. Scaglione, and K. Dostert, Guest Eds., "Broadband is Power: Internet Access Through the Power Line Network," *IEEE Commun. Mag.*, vol. 31, no. 5, May 2003.
[4] IEEE ComSoc, "Best Readings in Power Line Communications," http://www.comsoc.org/best-readings

BIOGRAPHIES

LUTZ LAMPE [M'02, SM'08] received his Diplom (Univ.) and Ph.D. degrees in electrical engineering from the University of Erlangen, Germany, in 1998 and 2002, respectively. Since 2003 he has been with the Department of Electrical and Computer Engineering at the University of British Columbia, where he is a full professor. He is (co-)recipient of a number of Best Paper Awards, including awards at the 2006 IEEE International Conference on Ultra-Wideband (ICUWB), 2010 IEEE ICC, and 2011 IEEE International Conference on Power Line Communications (ISPLC). He was awarded the UBC Killam Research Prize in 2008, the Friedrich Wilhelm Bessel Research Award by the Alexander von Humboldt Foundation in 2009, and the UBC Charles A. McDowell Award of Excellence in Research in 2010. He is an Associate Editor for *IEEE Wireless Communications Letters* and *IEEE Communications Surveys and Tutorials*, and has served as Associate Editor for *IEEE Transactions on Wireless Communications* from 2007 to 2011, *IEEE Transactions on Vehicular Technology* from 2004 to 2008 and the *International Journal on Electronics and Communications* from 2007 to 2011. He was General Chair of ISPLC '05 and ICUWB '09. He is Chair of the IEEE Communications Society Technical Committee on Power Line Communication.

ANDREA M. TONELLO [M'02] received his Doctor of Engineering degree in electronics in 1996 (summa cum laude) and Ph.D. in telecommunication engineering in 2002 from the University of Padova, Italy. In 1997 he was a member of technical staff with Bell Labs, Lucent Technologies, working on the development of baseband algorithms for cellular handsets, first in Holmdel, New Jersey, and then within the Philips/Lucent Consumer Products Division in Piscataway, New Jersey. Then, until December 2002, he was with the Bell Labs Advanced Wireless Technology Laboratory, Whippany, New Jersey. He was promoted in 2002 to technical manager, and was appointed managing director of Bell Labs, Italy. He conducted research on wireless systems and was involved in the standardization of the evolution of 2G and 3G cellular technology. In January 2003 he joined the University of Udine, Italy, where he is currently an aggregate professor and founder of the Wireless and Power Line Communication Laboratory. His research focuses on next-generation wireless systems, infomobility and vehicular networks, and PLC including home networks and smart grids. He has been involved in several European collaborative actions through FP5-FP7 EU funded projects and within the Institutional Human Resources Strategy Group that aims at implementing the European charter for researchers and the code of conduct for the recruitment of researchers. He received several awards, including a Lucent Bell Labs Recognition of Excellence award in 2003, a Distinguished Visiting Fellowship Award by the Royal Academy of Engineering (United Kingdom) in 2010, and a Distinguished Lecturer Award by the IEEE Vehicular Technology Society in 2011. He co-authored the papers that received the best student paper awards at IEEE ISPLC '10 and '11, the IEEE Vehicular Technology Conference 2011 Spring MIMO track best paper award, and the 2007 *EURASIP Journal on Advances in Signal Processing* best paper award. He has held chairing positions at conferences; in particular, he was TPC Co-Chair of IEEE ISPLC '07, Chair of the Workshop on PLC '09, and General Chair of IEEE ISPLC '11. He serves as an Associate Editor for *IEEE Transactions on Vehicular Technology*, and is on the editorial board of *ISRN Communications and Networking*. He is Vice-Chair of the IEEE Communications Society Technical Committee on Power Line Communications.

DON SHAVER [SM] is a Texas Instruments (TI) Fellow and chief architect for TI's Smart Grid business unit, where he is responsible for systems-level concepts and defining new products. He represents TI's smart grid solutions across industry standards organizations such as IEEE, ITU, PRIME, G3, and NIST, and drives TI's influence on governmental standards and regulatory activities. During his 34-year career with TI, he has held various positions in both product-specific and research and development organizations. He has initiated and directed new technology businesses, and international standards development in wireless and wireline communications, and developed systems, software, and application-specific processors in defense, geophysical, and communications applications. He has been awarded 15 patents. An active IEEE member for 42 years, he is Vice-Chair of the IEEE Computer Society Dallas Chapter. He earned a Bachelor of Science in electrical engineering as well as a Master of Science and doctorate degree in systems and information science, all from Syracuse University.