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Editorial

Advanced Signal Processing and Computational Intelligence Techniques for Power Line Communications

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Power line communications (PLC) is defined as data communication over power lines. The main reason to consider the medium "power line" for communication purposes is the extremely high penetration of the power distribution grid in most parts of the world. From urban to remote rural areas, power supply lines reach practically every household and thus are available as potential "carrier" of communication signals. This argument extends to buildings (homes, businesses) and mobile entities such as automobiles, ships, airplanes, or even spacecrafts, where electrical wiring enables deployment of PLC systems for internal communication.

The concept of PLC is not new and has been applied by power utilities for almost a century, mainly for sending control messages over medium and high voltage lines. In the late 1990s, with the deregulation of the telecommunication and energy markets in Europe, power utilities became more seriously interested in providing additional services through their lines. However, due to unrealistically high expectations on PLC as "last-mile" solution for high-speed Internet access, together with an unclear regulatory environment, lack of standards, and underestimation of the technical difficulties, the initial enthusiasm gave way to skepticism towards the viability of PLC for fast Internet access.

Today, we witness a cautious optimism regarding the future of PLC. This has several reasons. First, PLC is not only a last-mile technology but much more. While broadband Internet access over power lines remains an important application and current wide-scale field trials indicate commercial viability, power utilities, PLC vendors, and academic researchers are working together closely to unleash the full potential of PLC for efficient distribution-grid management and monitoring. Home networking is another major application for PLC and various consumer electronics giants are participating in the sophistication and standardization of PLC technology. Deployments of command-and-control PLC systems are expanding beyond classical home automation to, for example, lighting control in industrial premises and airfields, and other markets such as PLC for in-vehicle communication are currently explored. Second, the potentials of PLC are looked upon more realistically and the challenges of PLC are better understood. This concerns, for example, the differences in electrical wiring in different parts of the world and the characteristics of the power line as medium for data communication. Third, standardization for PLC is underway, driven, for example, by ETSIs Technical Committee on Power-Line Telecommunications and three IEEE working groups. Last but not least, there is a growing community of academic and industry researchers with backgrounds in various disciplines (signal processing, power engineering, electromagnetics, etc.), who are working on intelligent PLC solutions to enable the applications mentioned above. This special issue is evidence of this trend.

From a communications-engineering point of view, the most salient feature of PLC is the "hostile" channel. Different from other wired media, power lines were not designed for carrying broadband electromagnetic waves used for data transmission. The communication channel is characterized by high-path loss, severe frequency selectivity, and composite additive noise which includes impulse, narrowband, and colored background noise components. Furthermore, short-term (synchronous with the mains) and long-term channel variations occur.

This special issue contains seven papers, selected from 27 submitted papers, which are dedicated to advanced signal processing techniques to cope with such a harsh transmission environment.

In the first paper entitled "Wideband impulse modulation and receiver algorithms for multiuser power line communications," A. Tonello proposes a wide-band impulse-based code-division multiple access (CDMA) transmission system for multiuser indoor PLC. The large signal bandwidth allows to exploit frequency diversity and make the system robust to narrowband interference. Robustness against impulse noise is achieved due to error correcting coding and CDMA spreading. These favorable features come at the price of increased detection complexity. Therefore, the author presents suboptimal frequency-domain receiver algorithms with reduced complexity, which render the proposed impulse-based modulation scheme an interesting alternative for PLC.

R. Pighi and R. Raheli present powerful sequence detectors for coded single-carrier PLC in their paper "Linear predictive detection for power line communications impaired by colored noise." The effect of quasistationary colored noise on low- and high-voltage lines is explicitly taken into account in the joint equalizer-decoder design, and optimal and simplified receiver front ends and branch metrics for (reduced-stated) sequence detection are derived. The potential performance improvements due to receiver adaptation to colored noise are theoretically analyzed and confirmed by bit-error rate simulations.

The next paper is "Resource allocation with adaptive spread spectrum OFDM using 2D spreading for power-line communications" by J.-Y. Baudais and M. Crussière. Similar to telephone or wireless communication systems, multicarrier modulation is a very popular approach to deal with the frequency selectivity of the channel also for PLC. Assuming a quasistatic power line channel, the authors propose loading algorithms for spread spectrum orthogonal frequency division multiplexing (OFDM) with the distinct feature that spreading is done in time and in frequency direction (2D spreading). This additional degree of freedom compared to 1D spreading allows finer adaptation of the transmission parameters to the channel realization. The presented algorithms perform subcarrier, spreading-code, bit and energy allocation, and are shown to improve the data rate over non-spread loaded systems for fixed error-rate performance.

The fourth and fifth papers deal with synchronization for PLC multicarrier systems taking the particularities of PLC channels into account.

J. A. Cortés et al. investigate in "Analysis and design of timing recovery schemes for DMT systems over indoor power-line channels" the effect of short-term channel variations on the sampling-time synchronization in multicarrier systems. Short-term variations originate from the dependence of device impedances on the main voltage and thus are cyclic in nature. It is argued that short-term channel variations mislead conventional closed-loop timing synchronization schemes for multicarrier modulation unless the loop bandwidth is sufficiently small, which in turn makes them sensitive to jitter noise. To better cope with the cyclic channel variations, the authors propose two modifications, namely, the introduction of notch filters to the timing loop and an improved phase estimator. Numerical results using 24 measured channels show that data rate can be significantly increased with the modified timing synchronization.

While the previous paper considered high data-rate PLC transmission for, for example, in-home entertainment systems, the paper "Fast burst synchronization for power line communication systems" by G. Bumiller and L. Lampe is concerned with synchronization in low data-rate distributed PLC systems employed in, for example, command-and-control and power-grid management systems. The authors submit that in order to achieve reliable synchronization of asynchronously transmitted OFDM packets (or bursts) in a PLC setting with as little overhead as possible, conventional preamble signals are not well suited. Instead, a new semianalytic framework for preamble design taking into account the particularities of the power line channel is developed. An extensive performance comparison between an exemplary preamble design and two conventional synchronization preambles makes the advantages of the proposed framework explicit.

The final two papers are dedicated to the problem of error-correcting coding for PLC systems. More specifically, the use and optimization of the recently rediscovered low-density parity-check (LDPC) codes are investigated.

In the paper "Improving a power line communications standard with LDPC codes" C. Hsu et al. consider the application of LDPC codes to the robust-OFDM (ROBO) mode of the Homeplug 1.0 standard, which provides modest throughput in worst-case transmission scenarios. While the current standard prescribes the concatenation of Reed-Solomon and convolutional codes, the authors show that replacing this scheme with LDPC codes results in throughput, reliability, and complexity improvements. Key ingredient is a clipping procedure devised by the authors to reduce the distorting effect of impulse noise on decoding metrics.

A. Sanaei and M. Ardakani authored the last paper "LDPC code design for nonuniform power-line channels," which presents a coding scheme for multicarrier modulation that allows for using a single LDPC code over the, in frequency direction, nonuniform channel. Instead of considering bit-loading, the nonuniformity of the channel quality is dealt with in the code design. More specifically, the frequency subchannels are grouped (into a small number of groups) according to the signal-to-noise ratio, and different LDPC degree distributions are used for bits assigned to subchannels in each group. The code optimization is formulated as an iterative linear program, which can be efficiently solved. Applied to typical indoor power line channels, it is possible to closely approach capacity with this design.

We believe that the collection of papers in this special issue illustrates the great variety of topics (and problems) in PLC for which tools from advanced signal processing are applicable and needed. Perhaps, the reader will also have noticed that in most contributions the system model does not include *all* of the characteristics of power line channels mentioned earlier. While this is often justified due to different impacts on performance depending on the application scenario in mind, it also alludes to the fact that propagation and channel modeling for PLC is still a very active field of research and that standard models are not available yet. Similar is true for models of unintentional radiation, which is an extremely important topic regarding electromagnetic compatibility of PLC. Hence, further research on advanced signal processing techniques for PLC, carried out in tandem with the refinement and standardization of channel and radiation models, is called for. We hope that this special issue encourages and stimulates many colleagues to contribute to this effort.

Finally, we would like to take this opportunity to express our thanks to all authors who have submitted contributions to this special issue and to our colleagues who devoted their valuable time reviewing these submissions.

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Lutz Lampe received the Diploma and the 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 currently an Associate Professor. His main research interests lie in the areas of communications and information theory applied to wireless and power line transmission. He is corecipient of the EURASIP Signal Processing Journal Best Paper Award 2005, the Best Paper Award at the IEEE International Conference on Ultra-Wideband (ICUWB) 2006, and the Best Student Paper Awards at the European Wireless Conference 2000 and at the International Zurich Seminar 2002. In 2003, he received the Dissertation Award of the German Society of Information Techniques (ITG). He is an Editor for the IEEE Transactions on Wireless Communications and has served as an Associate Editor for the IEEE Transactions on Vehicular Technology from 2004 to 2007. Since 2004, he has been Vice Chair of the IEEE Communications Society Technical Committee on Power Line Communications. He was General Chair of the 2005 International Symposium on Power Line Communications and Its Applications (2005 ISPLC), Cochair of the General Symposium of the 2006 IEEE Global Telecommunications Conference (Globecom 2006), and Technical Program Committee Cochair of the 2007 IEEE ISPLC.

Klaus Dostert received his M.S. degree from RWTH Aachen, Germany, in 1976, and the Ph.D. degree from the University of Kaiserslautern in 1980. During the following years, he worked as a postdoctoral fellow in the fields of RF communications, signal processing, and data transmission over power lines. In 1991, he completed his habilitation dissertation on RF communications, and became a Full Professor at the University of Karlsruhe in 1992. During the past 15 years, his work centered around various aspects of PLC, including channel emulation, system design, and EMC analysis. Dr. Dostert is an IEEE Senior Member and has published more than 120 scientific papers and two books on power line communications. In 2000, he was a guest lecturer at the Technical University of Vienna. For the time period 2007-2008, he has been selected as a ComSoc Distinguished Lecturer.

Halid Hrasnica graduated in 1993 in electrical engineering at the University of Sarajevo, Bosnia and Herzegovina. From 1993 to 1995, he was working in Energoinvest Communications in Sarajevo as developing software Engineer for communications systems. In 1995 he joined the Chair for Telecommunications at Dresden University of Technology, Germany, where he received his Ph.D. degree in electrical engineering and information technology in May 2004. In February 2006, he joined Eurescom GmbH in Heidelberg, Germany, where he works as Programme Manager responsible for projects on future telecommunications networks. His main areas of expertise include the design of communications protocols, development of routing algorithms, performance evaluation of broadband communications networks, network planning and optimization. He published a large number of scientific papers and is Member of IEEE Technical Committee Powerline Communications and is TPC Member for IEEE International Conference on Communications, GLOBECOM, ISPLC, AccessNets2007, and SPIE's ITCom conference. He is the main author of the book *Broadband Powerline Communications*, published by Wiley and Sons in 2004, and main contributor to Wiley Encyclopedia of Telecommunications 2002, on the same topic. He was involved as researcher and project manager in several national and international R&D projects in various frameworks as well as industry projects.