Summary of Contributions
at
ISPLC 1997 – 2001

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Abstract
This contribution gives an overview of the main developments in Power Line Communications presented at the ISPLC 1997-2001. These meetings were organized in 1997 (Han Vinck, Essen, Germany), 1998 (Gen Marubayashi, Tokyo, Japan), 1999 (Bahram Honary, Lancaster, England), 2000 (Tom Coffey, Limerick, Ireland), 2001 (Hans Ottosson and Göran Lindell, Malmö, Sweden). The number of participants was about 100 at these meetings.

Contents

Introduction

In this summary an overview of the lectures presented at ISPLC 1997-2001 is given, and we concentrate on the main lines in the development.

The symposium on "Power-Line Communications and its Applications" ISPLC is a natural result of the discussions between research groups on communications, industrial engineers and energy providers interested in this particular field of communications. The great variety of applications and the falling of the monopoly position of the national telecommunication organizations in the year 2000 are obvious reasons for an increased interest from industrial and academic research and development institutes. Clearly, the main focus was on the connection between house and transformer as a solution for the “last-dirty-mile” problem. To solve this in a commercially attractive way seems to be very hard for various reasons. Again new interest arises because of the recent developments in In-House networking. There are several interesting aspects connected with this symposium. We mention a few of them.

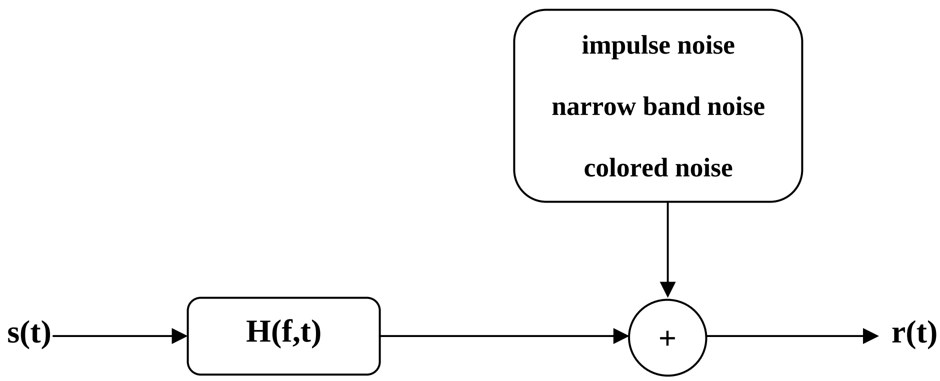
Firstly, we deal with a very complicated channel that mixes the nasty behavior of a power-line with that of a communication channel. We are still far behind the developments in ordinary telephony as far as communication speed concerns. In a period of twenty years, modern modulation techniques increased transmission speed for traditional telephony with a factor of ten. The DSL techniques will further improve this figure. Moreover, in recent years many research institutes concentrated on mobile communication systems like GSM and UMTS. The transmission environment for power-line communications seems much worse than that for mobile communications, so that, not only to utilize existing high technologies but also to create novel technologies will be needed.
Around 1985 one considered power-line communications to be an application field of the spread spectrum technology. For an hostile medium such as electrical power-line and/or urban mobile radio environment an exquisite modulation technique will be required and the spread spectrum modulation technique seemed to meet the requirement well in a broad sense. Several Japanese manufacturing companies as well as the Japanese Post Office Ministry worked enthusiastically toward making the plan for the power-line home bus system. A commercial spread spectrum power-line home bus system has been developed by NEC Home Electronics, Ltd. However, at that time there was no demand for the technology.

Secondly, an important aspect of power-line communication is the question of standardization. Since there are different international standards and power-line regulations, we also have a great variety of different products and applied communication techniques. It is interesting to compare standards and performances for the respective standards and systems. Like in consumer electronics, world-wide standards give the opportunity to develop low cost equipment and to penetrate the market on a large scale. The existing power-line infrastructure is growing in importance as a commercially viable, low-cost option. There is no doubt that the last few decades have brought tremendous developments in power-line communications, however none of us can begin to predict the scope of the advances to be achieved at the start of the 21st century. There is one certainty: these advances will be driven more by the global business needs of communications users and service providers than they ever have been in the past.

Thirdly, the symposium succeeded in attracting a high (60) percentage of industrial participation, including Japan, Korea and the USA. It is the mixture that makes this symposium to a unique opportunity to discuss the various systems and stimulate research in the field of power-line communications. The main goal is to exploit the ubiquitous electrical power-line network as a means for high-speed data communications. As we turn to increasingly hostile media to meet mankind's veracious appetite for communication, we must continue to develop ever more ingenious technological tools.

1. Measurements, Models, Channel Transfer Characterization

To be able to design and predict performance of communication systems it is of vital importance to have a thorough understanding of the channel characteristics. In power-line communication the received signal is often modeled as the sum of a filtered version of the transmitted signal and interfering signals (different kinds of noise). Due to the power-line environment the channel characteristics can be both time- and frequency-dependent, and also dependent on the location of transmitter and receiver in the specific power-line infrastructure. Hence, the power-line channel can in general be described as a random time-varying channel having a frequency-dependent signal-to-noise ratio over the communication bandwidth. The series of papers below, which are very briefly summarized, illustrate the significant amount of work being done aiming to increase our knowledge of the power-line as a communication channel. It can be observed that there are an increasing number of papers with focus on the high frequency range (roughly 1-30 MHz). As a historical note, let us here mention that in September 1997 NOR.WEB launched its pioneering 1 Mbps PLC system ("last mile" access).



A general channel model.

<u>Low frequency range</u>

Hooijen (1997) reports on noise and transfer-function measurements in the CENELEC band. The residential power circuit is considered, and the measurements were made during a 3-month period in the city of Amsterdam, the Netherlands. Background noise, impulse noise, noise synchronous to the power frequency (50 Hz), and narrow-band noise are described and characterized. Measurement results indicate that signal attenuation levels ranges from about 40 to 100 dB/km.

Arzberger (1997), Dostert, Waldeck, and Zimmermann present measurement results illustrating characteristic properties of impedance, attenuation, and noise. The measurements are made in a low-voltage energy-distributing network, and the studied frequency range is 20 kHz to 150 kHz. Impedance measurements of low-voltage access points are presented and circuit models are derived. Results illustrating the time varying frequency-dependent attenuation are presented. This paper also contains an analysis of the noise statistics.

Ramseier (1998), Sabbattini, and Imboden describe a method based on cross-correlation to measure the impulse response of the power-line channel. Also, joint time-frequency analysis is here used as a tool for feature extraction of measured power-line noise. The proposed measurement set-up has been tested and used in a wide range of locations by ABB.

Moreau (1999) and Rousseau focus on the description of a PLC test bench used by Schlumberger to characterize PLC technologies. Considered application is mainly communication on the low voltage network within the CENELEC A band, supporting utility metering applications.

Yavuz (2000), Kural, Çoban, Ercan and Şafak report on initial measurement results on power-line noise (background noise, synchronous noise), signal attenuation and phase shift. Frequencies up to 250 kHz are investigated. This paper also briefly reviews existing standards, and channel models.

High frequency range

Dostert (1998) examines the physical properties of distribution grids for telecommunication applications. Measurements and channel models for frequencies up to 20 Mhz are presented, and model parameters are estimated (e.g., delay parameters in an echo-based model). One of the conclusions is that several Mbps appear realistic in typical European power distribution grids.

Philipps (1998) considers measurements and models for in-building power-line communications for frequencies up to 30 MHz. Measured impedance characteristics at different locations are reported, as well as noise and transfer function characteristics (both amplitude and phase). Impedance mismatch and some of its consequences are presented and discussed.

Philipps (1999) models the characteristics of power-line channels inside of buildings. The considered frequency range is up to 30 MHz. Two approaches are used to describe the transfer function; an echo model, and a series resonant circuit respectively. The noise model used is based on a piece-wise constant power spectral density. Positive results are reported when comparing the models with measurements.

Voglgsang (2000), Langguth, Körner, Steckenbiller, and Knorr report on a statistical noise model for the indoor power-line channel in the frequency band from 1 MHz to 30 MHz. Model parameters are derived from measurements (between line and neutral at different locations). The measurement setup for noise measurements of single disturbances are given, and the measurements were carried out in accordance with the German standards VDE 0871 and VDE 0877. A thorough examination of the background noise is also presented.

Philipps (2000) describes the development of a statistical channel model (transfer function and noise) of in-house power-line channels for frequencies up to 30 Mhz. The model is based on measurement results from a few hundred power-line channels. An echo model is used, and the noise is modeled as a sum of disturbances with different characteristics. This paper also reports on measurements on the impulse response of the channel, and parameters such as the average delay and delay spread are considered.

Zimmermann (2000) and Dostert focus on the time- and frequency- characteristics of the noise in the frequency range from some hundred kHz up to 20 MHz. Properties of background noise, and impulsive noise, are studied in detail. Various models for the noise are proposed, and a partitioned Markov-chain is used to model the time behavior of asynchronous impulsive noise. One of the conclusions obtained in this paper is that the noise scenario in power-line channels is mostly dominated by narrow-band interference and impulsive noise.

Gonzáles-Prelcic (2001), Mosquera, Degara, and Currais present the on-going efforts to obtain a proper software power line channel simulator adapted to the Galician low voltage mains network in the 2-20 MHz band. Focus is on the access from the last transformer to the customer premises. Several channel measurement results are shown. The impulse response is modeled as a sum of weighted and delayed pulses of different width.

Yazdani (2001), Naderi, and Honary present a mathematical model for obtaining the characteristic impedance of the power line channel. The frequency band 1 to 30 MHz is considered, and a power line analyzing tool (PLAT) for performance evaluation of power line communication is suggested. Channel characteristics of LV PLC in an in-house environment is addressed.

Prasad (2001), Srikanth, Krishnan, and Ramakrishna report on results based on frequency- and time-domain measurements in a campus underground power-line network in India. Signal and noise spectrum, as well as average power delay profile is presented. Measurement results obtained at different receiver locations are compared and discussed.

Tsuzuki (2001), Yamamoto, Takamatsu, and Yamada investigate the impedance characteristics of household-appliances and power line channels in the Japanese indoor PLC environment. The frequency band from 70 kHz to 35 MHz is considered. Transfer function results are also presented. Furthermore, characteristics of VVF (Vinyl insulation, Vinyl sheat, Flat) cables with two wires are illustrated and discussed.

Cañete Corripio (2001), Díez del Río, and Entrambasaguas Muñoz describe a model for high bit rate communication on the low-voltage distribution lines inside buildings. The model is flexible and it can handle, e.g., different topologies, transmission line characteristics, loads and noise sources. Time variations are also included in the model. Simulation results are presented and discussed.

Corlay (2001), Coudoux, Gazalet, Ruolt, and Haine consider a multipath model of the impulse response for indoor power-line communication in the frequency range 1 to 30 MHz. The measurement system used to obtain the parameters of the model is described, including characteristics of the coupling units. Model and measurement results are compared, both in the time-domain and in the frequency domain.

Assimakopoulos (2001) and Pavlidou study the attenuation and noise characteristics for a "typical Greek residence" loaded with widely used electric devices. Transfer function, impulse response and noise measurement results for frequencies up to 30 MHz is presented. An adaptive OFDM modulation scheme is proposed, and performance parameters such as bit rate and BER are estimated.
Lee (2001), Park, Lee, Lee, and Kim investigate indoor power line channel characteristics in the frequency band 10 to 30 MHz. Impulse response measurements are made using the pseudo-noise (PN) correlation method. Based on measurement data (laboratory environment) at different locations and time of the day, a multipath channel model is proposed and evaluated. Simulation results of the bit error probability, assuming QPSK modulation, are also presented.

Noise analysis
Marubayashi (1997) addresses the noise characteristics of the residential power line. Noise from more than 20 different electrical apparatus used in ordinary homes are also measured and investigated, and statistical parameters for each device is derived and tabulated (e.g., amplitude and duration).
Moriyama (1998), Kubota, and Sakaniwa propose a non-linear model to describe the harmonic noise and periodic signal fading caused by switching devices. Based on measured characteristics, and studies of the generative mechanisms, the model is designed and evaluated. It is indicated that the harmonic noise and periodic signal fading are well reproduced by the proposed model.
Ohno (1998), Katayama, Yamazato, and Ogawa present a noise model consisting of the sum of several cyclo-stationary Gaussian processes, where the variances are simple cyclic functions. This model is able to express time variant features of the noise. Based on noise measurements, the parameters of the model are presented, and it is concluded that the model approximates actual noise with high accuracy.
Katayama (2000), Itou, Yamazato, and Ogawa suggest to model non-stationary power-line noise as a sum of cyclo-stationary Gaussian processes. With only a small number of parameters, this model is able to reflect time variant features of noise waveforms.

Analyzing and simulation tools
Bumiller (1999) presents a power-line analyzing tool PLATO, developed by the company iAd GmbH. PLATO is used for channel estimation, channel emulation, and evaluation of communication systems in the frequency range 9 kHz to 30 MHz. The system is portable, PC based, and with real-time capabilities.
Philipps (2001) gives a detailed description of a hardware realization of a statistical power-line channel model (echo model based). Power-line channels in the frequency range up to 30 MHz are considered, and the performance and characteristics of the hardware fading simulator are presented.
Sebeck (2001) and Bumiller focus on a tool for power-line channel characterization in the frequency range 9 kHz to 30 MHz. They describe the latest developments concerning the tool iPlato (power-line analyzing tool from iAd GmbH) which have integrated functionality for, e.g., channel estimation, noise analysis and channel emulation.
Yavuz (2001) and Şafak describe a simulation software for BER performance investigations. The model is flexible, and the influence of a variety of parameters can be studied. In this paper the CENELEC frequency band is considered. BER simulation results are presented and discussed, assuming non-coherent modulation techniques and error correction codes.

Channel capacity estimations
Hooijen (1998) and Vinck present a channel model for the residential power line communication channel. Based on this model channel capacity bounds are calculated. The paper includes a detailed description of the European norm EN 50065. Bounds on the capacity (versus communication distance) is obtained by considering a best case, and a worst case, noise power spectral density, and applying the water-filling procedure. One of the conclusions is that a residential power line telephone system is *theoretically* possible.
Cañete (2000), Diez, and Entrambasaguas report on indoor channel measurements and models for frequencies up to 30 MHz. A model-based method to obtain the impulse response is proposed. Measured channel signal-to-noise ratios (frequency dependent) are presented, and channel capacity estimates are calculated. Shannon capacity (ideal) results are compared with bit rate estimates for a more explicit scheme using OFDM.
Esmailian (2000), Kschischang, and Gulak study in-building power line channels in the frequency range 1 to 15 MHz. Attenuation measurements are presented, as well as time- and frequency- domain noise measurements. Parameters and properties of background noise and impulsive noise are obtained. Channel

capacity estimates for best and worst case are calculated assuming a few μW of transmit power, and the results indicate that high bit rate communication appear to be feasible. .
Langfeld (2001) derives and outlines preconditions for system design, like constraints in power and bandwidth. An analysis of EMC constraints and its implications, as well as a discussion of the power-line noise environment, is included. Four reference channel models are proposed and evaluated by a capacity analysis, and the achievable data rate for an adaptive OFDM with QAM modulation is derived.

2. Cable and Network Characterization

To be able to use the infrastructure of power-lines as an information carrier, it is necessary to understand how signals propagate in this network. This in turn depends on several important factors such as, e.g., the properties of the cables that constitute the network, the network topology, and the connected loads. Much work has been devoted to investigations aiming at characterizing and modeling of cables and networks. The series of papers below (which are very briefly summarized) illustrate the development within this area.

Low frequency range

Dalby (1997) addresses the analysis of wave propagation over coupled line structures. A way of describing coupled line structures is presented, which avoids the problem of finding the eigenvalues for the **ZY** matrix. The analysis is made in the frequency domain, avoiding the problems encountered in programs such as EMTP or ATP, which are time domain programs and less suited for high frequency analysis.
Hooijen (1998) investigates the relationship between signal attenuation levels and RPC-network topology and -loads. Topologies like the radial network, the ring network, and the meshed network are described. Transmission line theory is used in the analysis, and several interesting numerical results are obtained and discussed. The theoretical results obtained in this paper are in conformity with measurements made earlier by the same author.
Duval (1998) considers the analysis and suitable mathematical tools for investigating PLC signal propagation in low voltage electrical networks. The paper gives a detailed presentation of models (lines, loads, networks) and tools (mathematical, numerical), combined with several numerical examples.
Chaffanjon (1998) aims to give a view about the practical means to improve the propagation conditions and to make LV PLC networks reliable. Electromagnetic consequences are described, as well as coupling-filtering devices. Results and lessons from experiments are discussed.
Barnes (1998) describes a physical model that represents a power distribution network channel by multi-paths and subpaths. The propagation effects in poly-phase lines and at discontinuities are discussed from the model´s perspective, as well as the results of initial network studies. The model seems to correctly predict observed phenomena such as transmission line effects and it provides interesting quantitative results.
Hannaford (2000) and Davies examine the performance of typical intelligent airfield lighting systems, where 50-Hz power is delivered via a current loop, on which is impressed control and data signals at a frequency in the region of several hundred kHz. From the analysis presented in this paper it is seen that fundamental circuit principles characterize the propagation of data signals.

High frequency range

Brown (1997) considers telecommunication applications on a multiple access basis over low voltage electricity distribution network. A high frequency conditioned power network solution based on directional coupling (or conditioning unit) is described, and performance results are illustrated.
Dickinson (1997) and Nicholson report on the steps required in order to determine the transmission line parameters for three phase distribution cables. The analysis assumes that the propagation is via the TEM mode.
Zimmermann (1999) and Dostert present a model of the transfer function (amplitude and phase) of power line communication links in the frequency range 500 kHz to 20 MHz. The model is derived based on multi-path signal propagation and cable losses. Good agreement between measured and simulated results are reported.
Hensen (1999), Schulz, Schwarze, Borchers, and Dickmann examine the transmission characteristics of medium voltage power-line cables with regard to high data rate communication. Measurement results are used to develop a passive model of a selective type of single-core cable. The cable properties in the frequency range up to 10 MHz are reflected by the model.

Matov (2001) considers a planning tool for high bit rate communication over power-line communication channels. Characteristics, performance and features are illustrated on a configuration of three cables connected in a star configuration, which is repetitive in the utility network, giving rise to a tree structure network.
Sartenaer (2001) and Delogne address a theoretical framework for the modeling of underground power-line access networks. A generic simulation tool is described which consists of several levels of abstraction: Maxwell´s equations, classical primary parameters, multi-dimensional transmission line equations, and the whole power-line access network.
Banwell (2001) and Galli address the problem of determining the exact conditions under which the power line channel may be considered a symmetric channel, i.e. exhibiting the same frequency transfer function from either side. Transmission matrices are used, and it is concluded that the power line channel is symmetric regardless of the topology of the link provided that the source and load impedances used to terminate the line are the same.
Banwell (2001) and Galli propose a frequency domain approach to the characterization of the power line channel. The approach is based on the use of transmission (or ABCD) matrices. It is argued that this approach has several advantages compared with the multi-path model which is specified in the time-domain.

3. Coding and Modulation Techniques

Coding and modulation techniques for the power-line communication channel aims at reliable information transmission using signals located within the available bandwidth, and complying with present (or future) regulations. Examples of aspects that usually are considered when selecting a specific technique are, the transfer function and noise/interference characteristics, the impulse response of the channel, the amount of time-variation of the channel, the desired bit rate, and the complexity of the receiver. Hence, channel models are in general required to be able to design communication systems with good performance. Among the potential candidates we have, e.g., solutions based on multi-carrier techniques and/or spread-spectrum techniques (see also chapters 5-6). The series of papers below (which are very briefly summarized) illustrate the development within the area of coding and modulation for the power-line channel.

Communication channel model

Brown (1998) considers some of the key factors which influence data transmission rates in the power-line environment when utilizing carrier frequencies above 1 MHz. The author seeks to compare a theoretical rationale with practical results where possible. Several aspects are considered, e.g., Hartley-Shannon theorem, network architecture, network noise, link power budget and EMC.
Rickard (2000) reports on results illustrating the loss, radiation and noise characteristics of low voltage cables, and the performance of a power-line communication system operating on these cables is examined. It is concluded that it is technically feasible to construct a power-line communication system to give useful performance on underground low voltage distribution systems.

Techniques

Sekizawa (1998), Yahagi, Hasegawa, and Kamitaira describe the development of a communication system using the Japanese 6.6 kV power distribution lines. A hybrid system is considered and its configuration and function is presented, including a discussion of system applications.
Lund (1999), Honary, and Darnell address how a well known adaptive error protection technique can be combined with synchronization on a single integrated circuit. The design of a multi-functional adaptive nested codec with high speed and low cost is described.
Lampe (1999) and Fischer study power and bandwidth efficient differentially encoded transmission over fading channels. Differential encoding of amplitude and phase is used. Several differentially encoded 16-ary signal constellations with incoherent reception are compared with respect to achievable channel capacity.
Lindell (1999) and Selander attempts to quantify some effects of additive non-white Gaussian noise on minimum Euclidean distance receivers. Two receiver structures are studied and compared with respect to robustness against narrow-band disturbances.

Chippendale (2000), Honary, and Scott present an adaptive scheme for the dynamic allocation of channel frequencies and forward error correction specific to power-line communications in marine vessels. By locating and employing a reliable control channel, frequency bands that exhibit a greater stability can be utilized for data transmission.

Baumgartner (2000), Griesser, and Bossert discuss the effects of iterative multistage decoding with respect to an underlying OFDM transmission scheme over the power line channel. Simulation results of the bit error rate (BER) both for the AWGN channel and for the power-line channel are presented.

Vinck (2000) and Häring describe a transmission scheme combining 4-FSK modulation with diversity and coding to make the transmission over power-lines robust against permanent frequency disturbances and impulse noise. The scheme is in agreement with the existing CENELEC norms. In this paper, permutation codes are used, and non-coherent detection is assumed.

Lindell (2000) investigates a coded modulation scheme which uses M-FSK signals in L sub-channels. Channel quality parameters (random) are used, and the receiver is assumed to perform non-coherent square-law noise-whitening combining. No estimates of the channel transfer function is used by the receiver.

Hesse (2001) and Schulz present simulation results for a direct sequence CDMA based power-line communication system. Several users are assumed to transmit data simultaneously and asynchronously over a noisy and frequency selective channel, and the effect of non-ideal power control is also studied. Receiver structures are considered, and an improved CMOE (constrained minimum output energy) detector is described and evaluated.

Umehara (2001), Kawai, and Morihiro consider the modeling and effects of a periodically varying channel fading and noise over a power line channel (due to e.g., electric appliances). Computer simulation results are presented, and the BER performance of non-coherent coded modulations, for various modulation types, is evaluated and compared.

Häring (2001) and Vinck analyze codes for impulsive noise channels. Performance bounds are derived and analyzed for coded transmission over the additive white Class A noise (AWCN) channel. A combination of codes designed for the AWGN channel and complex number (CN) codes is proposed, and an interesting connection to OFDM is pointed out.

Discrete multi-tone modulation

Petré (1999), Engels, Gyselinckx, and De Man propose discrete multi tone (DMT) as a means to obtain high data rates in the CENELEC A-band (9-95 kHz). To maximize the bit rate, a rate-adaptive loading algorithm is used. Simulation results indicate bit rates of several hundreds of kbps with a transmit power of about 100 mW in the best case scenario, and with about 10 – 100 W in the worst case scenario.

Sartenaer (2000), Horlin, and Vandendorpe investigate the use of DMT-FDMA in the context of wideband upstream power-line communications. Several issues are addressed, e.g., reception under ideal synchronization assumptions and a simplified noise environment, as well as equalizer structures. A tone allocation method is also proposed that intends to maximize the total bit rate under a fairness constraint between users.

Pay (2001) and Şafak study the effect of channel noise of impulsive character on the performance of a discrete multitone (DMT) system. The channel noise is modeled by the Middleton class A model, and a method for generating class A distributed random noise samples is presented. Furthermore, an expression for the sub-channel SER (symbol error rate) performance is derived and evaluated.

Rousseau (2001), Moreau, and Bellanger consider the characterization and optimization of multicarrier technologies applied to PLC communications in the CENELEC A-band. A multicarrier modulation scheme for the CENELEC A-band is described and evaluated. It is composed of 175 channels (OQAM constellations) of 400 Hz that covers a total bandwidth of 70 kHz (from 20 to 90 kHz). A short description of the PLC test bench used (Schlumberger RMS) is also provided.

4. Modem Design

Modem design and practical tests are indeed essential parts in the development of power-line communications. Over the years we have seen an increased activity which has lead to more advanced and mature technical solutions. Several companies have launched commercial products, whilst others are making field tests and are close to market introduction. This development is partly illustrated by the series of papers below (which are very briefly summarized).

Based on FSK

Görlitz (1997) describes the ENERCOM system for reading, transmission and billing of energy data developed by Goerlitz Computerbau GmbH. The system is build of single nodes as logical devices, and each node is an application device as well as a routing or repetition device. All nodes are equal in their networking role. A modem using SGS Thomson technology is used working in the CENELEC A-band. The ENERTALK protocol language is described, and practical experiences are reported.

Telkamp (1997) presents ATICON´s solution of a node for domestic applications, which integrates the power supply, power-line modem, line interface, application processor and an opto-galvanically separated i/o interface on a printed circuit board of 61x 113 mm. The system works in the CENELEC C-band, and a modem from SGS Thomson generating minimum frequency shift keying signals is used. A review of the EHS (European Home System) specification is also given.

Based on SFSK

Goffart (1997), Evens, Desneux, and Boxho present an integrated modem developed to support communication on the power-line. The circuit handles the physical and MAC layers as described in the IEC 1334-5-1 standard (spread frequency shift keying). The protocol handling is realized by the use of an embedded micro-controller with masked program ROM. The modem is implemented in a 0.5 µ CMOS mixed-mode process from Alcatel Mietec. Its digital programmable architecture enables the circuit to be adapted to alternate standards.

Goffart (1999) and Boscand is similar to the 1997 contribution summarized above.

Based on OFDM

Deinzer (1999) and Stöger report on a single-chip power-line transceiver based on OFDM (with differentially encoded amplitude and/or phase-modulation). Forward error correction is included and several coding rates are available. Data rates between 4.8 kbps and 107 kbps are attainable within a frequency range of 4 kHz to 38 kHz respectively. The integrated PLC modem is a mostly digital circuit implemented in a 0.6 µm CMOS mixed-mode process.

Galda (1999), Giebel, Zölzer, and Rohling present an experimental OFDM modem for the CENELEC B-band (95 to 125 kHz). The proposed system uses multilevel differential amplitude phase modulation (DAPSK), and does not require channel estimation in the receiver. A robust synchronization technique is proposed. System design aspects as well as performance estimates are given. This paper also contains a brief review of OFDM.

Dalichau (2000) and Täger introduce the first generation of PolyTrax PLC modems using conventional FSK modulation (in B-band), and the second generation using OFDM with QAM (in B- and D-band). The second approach has dynamic frequency allocation and automatic channel adaptivity. The two approaches are described and compared, followed by a brief description of additional features of the third generation PLC modems.

Bumiller (2001) and Sebeck consider a complete communication system for low and medium-voltage distribution lines, and a communication server to integrate different utility services and home automation software (the system is DLC-1000 developed by the company iAd). Convolutional coding, OFDM modulation (bandwidth flexible between 4 to 38 kHz), and MLSE decoding is used. The network management system is based on a master-slave concept. The network structure as well as the system components are described.

Based on DS/SS

Raphaeli (2000) and Grauer describe, and present the performance of, the ITM1 PLC modem from ITRAN Communications Ltd. A modulation technique referred to as adaptive code shift keying (ACSK) is used (a non-conventional direct sequence spread spectrum technology). The spectral range is typically 4 to 20 MHz, and the PSD after power line coupling and BPF coupling is around –63 dBm/Hz. Simulation and experimental results (in-home application) are reported.

Based on DMT

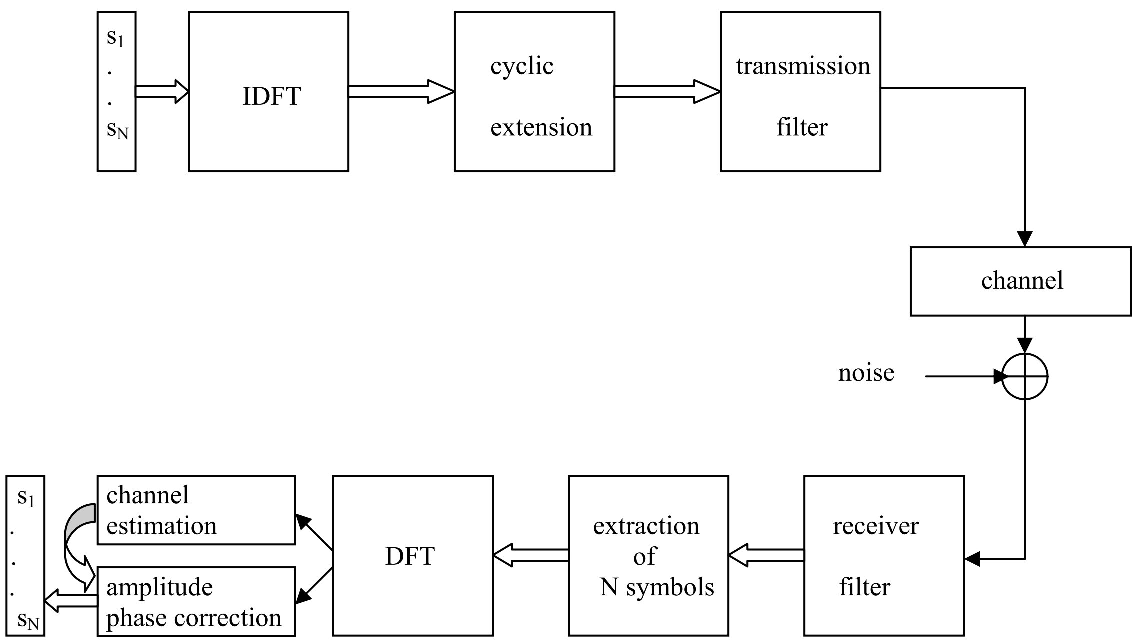
Kaplan-Güvenç (2001), Çoban, and Şafak provide a description and an analysis of a discrete multitone (DMT) system for digital communication over power-lines. The system is presently implemented as a lab-prototype and it operates within the CENELEC band (20 to 116 kHz). 32 carriers are used with 4 kHz spacing, and a rate 2/3 trellis code modulation (TCM) in conjunction with 8-DPSK is applied to each sub-carrier. AWGN and impulsive noise channels are considered.

General aspects

Beikirch (2000) and Voß focus on a controller area network (CAN) – transceiver for field bus power-line communications. The CAN is an object-oriented multi master system with random access. Timing problems are especially considered, and the signal delay chain is modeled and discussed. The authors report on two test environments for CAN-based power-line data transmission (low-speed interface, and high-speed interface), and an overview of power-line technologies used in the field bus area is also presented.

5. OFDM

Orthogonal Frequency Division Modulation (OFDM) is considered to be an attractive way to achieve high data rates for the powerline channel. Furthermore, OFDM is a standard for Digital Audio Broadcasting (DAB) and The American National Standard Institute selected OFDM for asymmetric digital subscriber lines (ADSL). Therefore, a lot of knowledge regarding implementation complexity and its use in "nasty PLC" environments is present in the research environments. Problems that influence the performance are the control of carrier power, frequency selective fading and impulsive noise. Another source of degradation results from narrow band interference caused by short and medium wave radio transmitters located in the same frequency band.



GENERAL OFDM TRANSMISSION MODEL

Performance analysis

Nomura (2001), Shirai, Itami, and Itoh propose a system where transmission power of each carrier of the OFDM signal is controlled so as to minimize the average SNR of each carrier under the constraint that the total transmission power is constant. It is shown that symbol error rate characteristics are much improved when an optimal power allocation to each carrier is used. The system uses channel state information to estimate the channel transfer function and noise power spectral density.

Lampe (2000), Fisher, and Schober examine the use of bandwidth-efficient, non-coherent multicarrier modulation (OFDM) over powerline channels. Both adaptive (using channel state information for optimal loading) and non-adaptive modulation are discussed and assessed. It is shown that channel coding significantly reduces the performance gap between adaptive and non-adaptive OFDM.
Sugimoto (2001), Katayama, Yamazato, and Okada consider adaptive mapping of data according to frequency and time dependency of the cyclo-stationary channel characteristics. The bit error rate of every sub-carrier is derived under the cyclo-stationary channel model assumption.
Häring (2000) and Vinck analyse the influence of impulsive noise on the OFDM transmission. As a model the Middleton Class A man-made noise model is used. It is concluded that a special treatment of impulsive noise is necessary. The authors describe a new iterative algorithm suited for mitigating the influence of impulsive noise on the OFDM transmission.
Dégardin (2001), Liénard, Degauque, Zeddam, and Gauthier optimize the OFDM transmission with respect to channel noise characteristics. Improvements based on Reed-Solomon codes and interleaving are exploited.
Galda (2001) and Rohling investigate the application of OFDM under the influence of narrow band interference. Available techniques for narrow band interference reduction are reviewed and compared in the sense of their complexity. Performance results from simulations are evaluated.
Langfeld (2000) and Dostert analyze aspects of synchronizing an OFDM system for powerline communications. Based on the analysis an acquisition method and a tracking algorithm based on pilot sequences are proposed.
Yazdani (2000), Mufti, Brown and Honary introduce a model for channel simulation purposes. An OFDM modem has been modeled and simulated with the UNIX based program called "COSSAP".
Burr (1999) and Brown consider two potential advantages of OFDM: its ability to overcome the channel dispersion limit, and its diversity advantage against both frequency-dependent propagation and narrow-band interference.

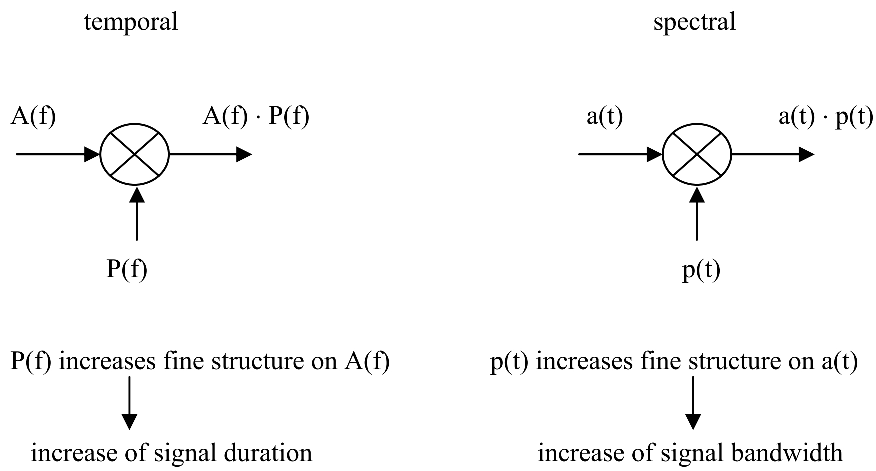
Comparison with other techniques

Schulz (2000) and Schwarze present a comparison between OFDM and CDMA for data communication on the medium voltage network. Simulations were carried out using channel transfer function measurements and noise of a selected medium voltage cable. The CDMA system showed a substantial advantage over the OFDM system concerning the transmitted power as well as the power spectral density which influences the radiated emissions. The choice for the CDMA or the OFDM depends mainly on the future regulations on radiated emissions.
Raphaeli (1999) and Bassin compare OFDM, single carrier and spread spectrum approach, each with proper coding, equalisation and synchronisation, and its adaptation to the powerline medium for frequencies in the 2-20Mhz band. The modulation technique depends on the application and Medium Access protocol. The conclusion is that spread spectrum has the advantage of low SNR, low emission spectral density and high reliability. The paper includes simulation and analytical results from real measurements.

6. Spread Spectrum Techniques

General aspects

Baier (1998) as an invited speaker gave an excellent tutorial on spread spectrum systems. Spreading techniques have an advantage in various areas of modern information technology like transmission, identification and estimation. One uses spreading techniques to overcome narrow band noise in the frequency domain or impulse noise in the time domain. In a way spreading can be seen as a diversity technique. To avoid interference problems (as can be expected for PLC) spreading allows a very low power spectral density in a broad band. The same advantage is valid for multi user environment.



Two different modes of spreading (Baier)

Sutterlin (1998) argues that the application of narrow band communications together with digital signal processing is the clear winner for powerline communication. He represents the Echelon corporation and stated that the spread spectrum techniques were found to be a detriment rather than a benefit in overcoming the harsh conditions of the powerline environment.

The powerline channel is power and band limited, so as not to interfere with electrical equipment. This limits the attainable processing gain of DSSS communication systems. Therefore, interference mitigation strategies have to be included to attain low bit error rates. *Burley (1999) and Darnell* detail a mathematical framework, using joint time-frequency analysis, for effective mitigation of non-Gaussian noise and interference. Two preprocessing techniques are introduced which complement the processing gain of a DSSS system.

Frequency hopping spread spectrum (FH)

In frequency hopping spread spectrum short pulses of different frequencies are transmitted that together use a broad spectrum. By choosing the respective frequencies, bad parts of the spectrum can be avoided.

Fallows (1998), Yazdani, Brown and Honary describe the effect of using an error correcting Reed Solomon code on the performance of FH spread spectrum systems. Although further study is needed, the results indicate that the code system has a robust error performance overcoming some of the problems associated with the PLC channel.

Marubayashi (1999) proposes a FH spread spectrum system based on the transmission of sequences of different frequencies, where every sequence has its own character. The system is an extension of the FH/Multilevel FSK system proposed by Goodman et al. (Bell System Techn. J. Sept. 1980) to a two dimensional scheme. *Ishikawa (2000) and Marubayashi* further extend this scheme and show an illustrative design example for PLC. *Hamamura (2001) and Marubayashi* give a construction method for a further parallelisation and thus improved bandwidth efficiency of the system, together with performance analysis.

Sequences for spread spectrum applications

Tsuziki (1997), Yoshida, Tazaki, and Yamada describe a sequence design with spectral shaping properties for DS/SS. The lower frequency components of the signal are compressed in accordance with the expected properties for the power spectral density of the noise. Special attention is paid to the cross-correlation properties. This paper may have broad applications, not only to PLC. *Suehiro (1998), Imoto and Vinck* propose a signal design for CDMA without co-channel interference.

Sasaki (1997) and Marubayashi use a set of R pseudo random sequences out of a set of M possible sequences to transmit information. The receiver uses M correlators to detect the active PN sequences and their polarity. Bit error rates are estimated and the system has been tested in an experimental environment He demonstrates a 64 kbps PCM voice data over the powerline with 440 kHz bandwidth (Japan).

Tachikawa (1998) and Inamura propose the combination of sequences from a Hadamard matrix with Pseudo Noise sequences to improve the complexity of correlation mapping in an M-ary/SS system. Basic complexity reduction is obtained by using the properties from the Hadamard transform. The system is tested for the Japanese allowed bandwidth (10-450 kHz).
Del Re (2000), Fantacci, Morosi, Seravalle, and Pieraccioli combine Orthogonal Variable Spreading Factor sequences with scrambling codes to minimise the Multiple Access interference and to provide flexible multicode allocation. Simulation results are presented for a frequency selective multipath fading channel and additive coloured Gaussian noise according to in building networks. In *Del Re (2001), Fantacci, Morosi, and Seravalle* the system has been compared with OFDM.
Pem (1999) and Darnell describe the performance of OFDM modems using complementary sequence sets under Gaussian and non-Gaussian channel conditions.

Communication system aspects

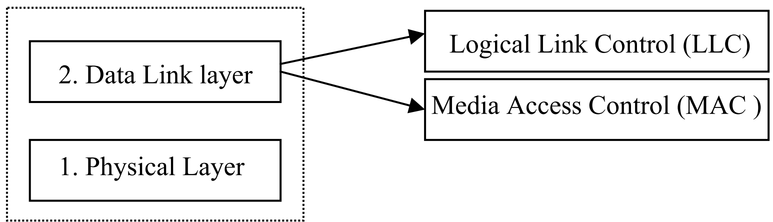
Hensen (1998) and Schulz demonstrate a prototype DS/CDMA processor and measured the influence of disturbances on the transmission conditions and the Bit Error Rate for continuous and burst transmission. The paper does not give detailed information on transmission speed and modem parameters. *Hensen (1999) and Schulz* applied CDMA to extend the ISDN-S_0 bus to overcome the problem of missing infrastructure for ISDN purposes inside buildings. Simulation results that took real channel conditions into account proved the usability of this technique. In *Hensen (2000) and Schulz* a description is given for a hardware design of a direct sequence spread spectrum Rake-receiver structure for simultaneous multi-user reception. The implemented Rake-receiver can resolve up to eight different propagation paths and therefore reduces the bit error probability. *Lee (2001), Kim, Oh, Kim, and Lee* design a receiver with FPGA for a DS-CDMA system.
Kanamori (1998), Nishimura, Takashima, Asuka, Wada, and Shimodaira report on a system design combining DS with band-splitting reception and majority demodulation at the receiver. Modem specification and performance for PLC are given in the paper.
Kusaka (1997), Kominami, Ikuta, and Arimura present the performance of a band limited DS/SSMA system for PLC using a Least Mean Square adaptive prediction error filter to reject narrow band interference. Bit error rates are estimated using several PLC channel models, as for instance a 29 inch TV set.
Radford (1997) a representative of Intellon, introduces the Spread Spectrum Carrier technology (SSC) and the basic concepts of the Consumer Electronic Bus (CEBus) standard. The SSC is based on a swept frequency chirp, implemented on a low cost integrated circuit. The description is simple and easy to understand. The bandwidth used is from 100 kHz to 400 kHz with an effective bit rate of 10Kb/s.

7. Hardware

Pérez (2000) developes a coupling device linking the PLC modem to the power line. The main problem considered is the variable impedance caused by on/off switching customer connections. The paper describes the design and implementation of an automatic impedance adapter for Medium Voltage equipment.
Bumiller (2001) and Deinzer present an analog and digital chipset based on the DLC-2A chip design which can be used as a stand alone OFDM power line modem for both the CENELEC band and the USA/Asia frequency band from 150 to 490 kHz. A description of the transmission method and the architecture is included.
The presentation by *Ghazel (2001) and Rouissi* deals with an optimised hardware design and DSP implementation of a narrow band power line modem. A Dual Carrier binary phase shift keying modulation with convolutional coding is proposed and measurements illustrate the performance for a 9600 baud modem.

8. Protocols

<u>Data link and medium access protocols</u>



The OSI data link layer can be subdivided into two sublayers: Logical Link Control (LLC) and Media Access Control (MAC). The LLC provides a reliable bit pipe for the upper network layer and the MAC sublayer provides a suitable media contention technique. Several techniques are known for the MAC, like Carrier Sense with collision detection (Ethernet) and token ring control. The performance of the selected protocol depends on the physical channel conditions and the protocol must be chosen with great care.

Mufti (2000), Yazdani, Brown and Honary describe a Data Link Layer protocol for a Powerline Local Area Network using a FEC-ARQ protocol for error handling and a token passing protocol for the MAC layer. The performance of the protocol is evaluated using an Additive White Gaussian Noise channel.

Propp (2000) uses token passing MAC for a reliable Multimedia-Capable Home Network. False synchronisation, missed transmissions, and near-far problems are well addressed with the token passing deterministic access scheme.

Coffey (1998), Griffin, and Moore introduce the structure of a Powerline Local Area Network (PPLAN). The focus of the paper is on the development of a MAC protocol for a token-passing bus network based on IEEE802.4. Measurements are presented for node throughput, network utilisation and the impact on network performance of the protocol's token holding time.

Hrasnica (2001), Haidine, and Lehnert argue that token passing and polling arbitration access methods show worse features for time critical services if the number of subscribers increases. Therefore, reservation MAC protocols for Powerline Communications are considered. Both polling and ALOHA based protocols are compared and methods for improvement of performance are given.

Tsuzuki (2000) and Yamada propose carrier sense spread spectrum (CSMA) with overload detection protocol to improve the conventional Ethernet's performance. The spreading factor is changed adaptively depending on the network loads. The contribution contains a performance analysis of the channel utilisation and delay time.

Langguth (2000), Steffen, Zeller, Steckenbiller and Knorr study the performance of Access Control in PLC. Simulation results are presented for a protocol based on two wireless standards IEEE 802.11 (CSMA/CA) and Bluetooth (Time Division Duplex, TDD). The choice of protocol depends strongly on the number of stations, the type of service and the required quality of service. Bluetooth is a good choice in a scenario with few stations, deterministic traffic and hard delay limits. The Internet access scenario with many stations, bursty traffic and low delay limits prefers IEEE 802.11.

Stantcheva (2000), Begain, Hrasnica, and Lehnert describe a MAC protocols for an OFDM based PLC network. The MAC layer consists of logical channels of 64kbit/s which can be allocated to the particular connections. The channels can be used in four different ways: circuit switched; packet switched; reserved channels; signalling channels for requests and transport of protocol information.

Lampe (2001) gives a Medium Access Scheme for TDMA with OFDM as transmission scheme. For efficient medium access signalling a solution is proposed based on CDMA in combination with superimposed codes.

Mushkin (2001) discusses the CSMA mechanism and analyses its limitations for PLC applications. A novel synchronised random access MAC mechanism is introduced. Advantage of the approach is that it is robust and efficient when more PLC networks share the powerline. Furthermore the new mechanism is independent of the specific physical and data link layer technology of the individual PLC network , thus enabling different technologies to share the same medium.

Network layer

Gallagher (2000), Moore, and Coffey discuss the development of an interface between the network and transport layer, which is used in the implementation of a powerline local area network. The developed interface provides independence from the users selected transport protocol. Is this way a flexible connection can be provided between the PLLAN to other existing networks, such as Internet and other Ethernet-based systems.

Sebeck (2000) and Bumiller present a network management system (NMS) based on a master-slave concept. Repeaters increase the range of the network where every slave can also be a repeater. A simulation is used to verify the functionality of the protocol and to optimize parameters.

Bumiller (2001) consider a network management system for telecommunication and internet applications. Different options and competing methods are discussed. A TDMA system with resource-administration realised centrally in the master is presented.

Ostertag (1998) and Imboden identify functional entities and requirements for a hybrid Distribution Automation (DA) / Demand Side Management (DSM) communication system. Special focus is put on the function of intelligent node controllers, the network management concept and the distribution line carrier communication.

Application layer

The application protocol DLMS (Device Language Message Specification) for communicating meters is described by *Somogyi (1997).* This protocol is standardized to provide a „common language“ for all kinds of communicating applications of the energy industry. The main objective is to insure interoperability of meters and other communications equipment of a meter communications network, built on the DMLS basis. How DLMS accomplishes it and what is the actual status (1997) of DLMS are the main topics of the paper.

Data security

Powerline networks present a number of security challenges due to their open, insecure bus structure. Two services that are necessary for these networks are: confidentiality; identity authentication and message integrity verification.

Newe (2000) and Coffey outline a realization of an identification scheme and presents a formal evaluation of the security and trust of the scheme. In *Dojen (2001) and Coffey* an overview of the cryptographic strength of symmetric ciphers suitable for PLC is given.

9. Standards

One of the most important topics for PLC is standardisation. The standardisation contributions dealt with the work of the Standardisation bodies like CENELEC and ETSI; comparisons of designed systems with standards and especially important from a regulators point of view, the question of radiated emission. This last topic will be of great importance for in-door applications. Another important question is what kind of modulation scheme can be used on powerlines. Is it suited for broadband applications or is the standard the limiting factor?

Bodies and their tasks

In *1997*, *Paul Fuchs* (Convenor IEC TC13 WG14) reviews the important standards in the field of Distribution Line Carrier (DLC) systems. It gives an interesting look at the state of the art in European standards at that time. His working group defines the use of a filter to avoid conflicts between home systems and utility systems.

Harris (1999) summarizes the regulatory regime that allows the deployment of PLC systems within the UK. Services delivered via PLC need to be operated under a specific license. The licenses are part of the responsibility of the Office of Telecommunications (OFTEL). An additional regulatory issue is the potential for radio interference from PLC systems at frequencies in the HF radio band. The Radio communication Agency (RA) has the responsibility to keep the radio spectrum free of pollution. The RA studied levels of radio emission from PLC systems. These have shown radiated signal levels significantly in excess of those levels that existing users of the radio spectrum believe that they are able to tolerate. A standard is under construction that produces a technology neutral specification for the RF emissions that might be seen from the PLC systems and which can be applied to current systems and future developments.

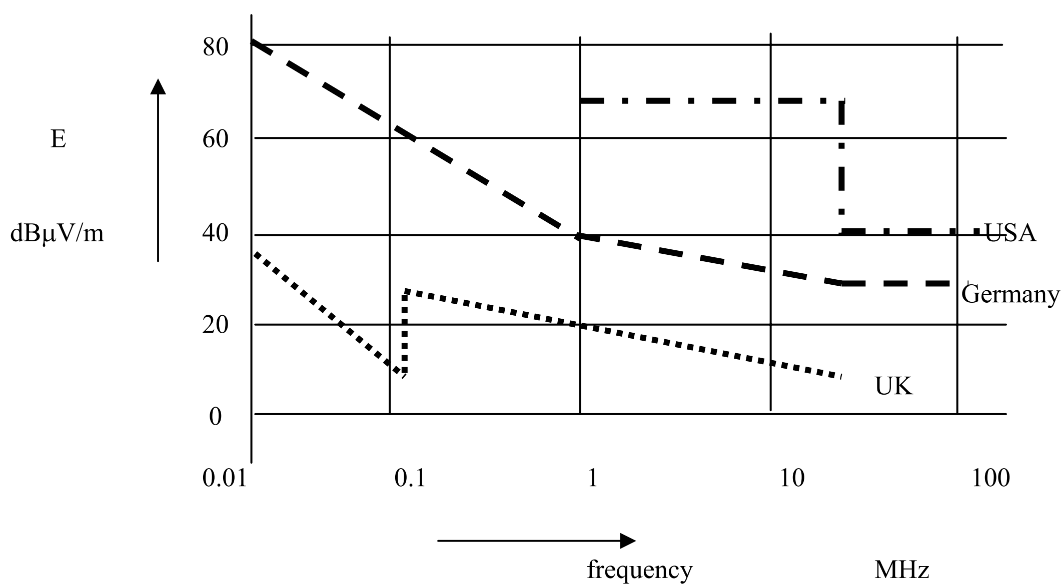
Comparisons with standards

Giebel (2000) and Rohling show in a detailed analysis how an OFDM signal fulfils the regularity requirements. Calculations show that the maximum transmit power spectral density in the frequency range of 150 kHz to 30 Mhz is in the range of measurements of the channel noise.

Heffernan (2000) and Burton propose the development of a fieldbus physical layer standard, which complies with the CENELEC EN 50065-1 requirements. Current developments are reviewed to put the proposal in a proper context. The paper provides a technical proposal on how the EHS physical and data link layer protocol can be used to specify a powerline physical layer solution for fieldbus networking which can be incorporated into the fieldbus standards.

Radiated emission

Radiated emission is one of the main obstacles in the development of PLC, since it represents a “electromagnetically open” structure. This means that the PLC system has to be protected against unwanted interference, but also that the PLC system itself has to reduce radiation such that other services are not affected. At the moment several regulations exist and we give the regulations for USA, Germany and the UK in the following figure (Dostert ISPLC2001).



Electrical field limits for radiation from wirebound communication in different countries.

Radio broadcasting signals absorbed by the power-line can cause communication problems when high frequency PLC signals (above 1MHz) are used. If such narrowband disturbances are too strong, then some kinds of counter-actions are in general required. Hence, methods are needed which can model, and predict the occurrence and consequences of similar disturbances. These kinds of problems are also well-known “the other way around”; if the levels of radiated PLC signals are too strong then we talk about EMC-related problems. The series of papers below, which are very briefly summarized, illustrate some of the important work that has (and is) been done within this area.

Lauder (1999) and Sun perform tests to investigate the relationship between the levels of signals fed into mains wiring and the resulting levels of radiated emissions. The conclusion is that for PLC systems operating above 150 kHz, using practical levels of signals injection, special frequency allocations will be required. The paper contains a modelling of radiated emission characteristics resulting from different types of networks and wiring in buildings.

Vick (2001) investigates magnetic field measurements and compares these with the results when using simple models for the 230 V mains wiring of households. Furthermore, the results were related to the limits of German NB 30, which regulates the emission of lines for telecommunication purposes.

Fenton (2001) and Brown provide an overview of existing emission standards, measurements and their applications by national regulators. It furthermore describes aspects of benchmarking high frequency radiated emissions from wireline communication systems in the near and far fields.

Rickard (1999) and James present a pragmatic approach to setting limits to radiation from PLC systems. Experimental data is presented illustrating the signal levels required to achieve a reasonable reach on the cables and the likely radiated field strengths that would result in the near and far fields. The same topic has been considered by Roper (2001).

Roper (2001) suggests a method of determine the transfer function for typical In-building wiring infrastructures and details results obtained from practical measurements, which in turn further enables a comparison of the near and far field radiated emissions in urban and rural environments. Measurements are analysed in order to determine the regression of the radiated emissions and to compare practical results with theoretical predictions in both the near and far field domains.

Hensen (2001) and Schwarze deal with EMC for medium voltage single-core cables. The paper also contains measurements with an OFDM transmission system. The radiated magnetic field can be predicted using a coupling factor that is determined by measurements using sinusoidal signals.

Issa (2001), Chaffanjon, and Pacaud study radiation due to the injection of signals onto a low voltage buried cable. Measurements are compared with predictions from a developed model. It is shown that electromagnetic fields resulting from differential injection are much less important than those created by a common one.

Brown (2000), Yazdani, and Honary details some of the work undertaken to investigate possible coexistence criteria which may facilitate the rapid deployment of the new wireline access technologies in harmony with the traditional wireless (radio) broadcast and communication services. This paper focuses particularly on the proposed power-line telecommunication (PLT) solutions.

Burr (1998), Reed, and Brown address HF broadcast interference on LV mains distribution networks. This paper describes the results of measurements made on the mains network to characterize the interference encountered at frequencies above 1MHz. Several measurement results, and statistical results are presented. One of the conclusions is that HF broadcast signals seem to be one of the most significant interference sources found on the mains in this part of the spectrum.

Yazdani (1999), Brown, and Honary suggest a methodology for comparing the theoretical (calculated free space), near and far field propagation characteristics of high frequency radio waves, with measured values. This is then utilized to develop a high frequency radio communications link benchmark for the assessment of the potential impact of a wide range of wireline services.

Gebhardt (2001) presents magnetic radiation measurement results of a residential building. The signal is injected within the house, and the field is measured outside the building. The three spatial polarizations of the magnetic field of a residential building are investigated separately depending on the distance from the building. The measurement method is described, as well as a model by linear antennas.

10. Field Trials

Field trials are an important source of information about the cost effectiveness and quality of a communication system based on powerline communications. These trials are very expensive and therefore the reports are scarce and hard to find in literature. Some trials were reported during the ISPLCs.

Wenker (1997) and Härry report on a field trial (1200 participants) using the AMDES (Landis and Gyr) 2-way communication. The system was used for load control, tariff switching and remote meter reading. The pilot project was mentioned a success and showed the feasibility of reliable communication on the energy supply network.

Propp (1997) describes an automated meter reading system in northern Spain using a 19.2 kbps throughput powerline communication technology. Customers were provided with information on elapsed consumption and cost, the current time-of-day rate, alarms, and messages sent by the utility, and allowed for load control for energy management. He also includes a description of the communication structure using the OSI layer model (Physical- Data Link- and Application layer).
Chudi (2001) covers technical results and practical aspects from a field trial with about 20 customers in villas and apartment houses in Danderyd, Stockholm, Sweden. This contribution also deals with the commercial aspects of a large introduction of PLC. Initial experiences are reported, and a business model is discussed.
Kamphuis (2001), Warmer, and Akkermans address PLC-based services that are customer-oriented rather than purely technology-driven. He reports on the SMART project that aims to develop and test PLC, in a full-scale real-world field experiment. It is considered as one of the component technologies for future Internet-based electronic services for smart buildings. The SMART building technology is rolled out at a four-storey building with about 150 office workspaces. The SMART system provides several building and energy management capabilities. At the customer side, all office users have a personal interface to the SMART building system.

11. Overview

The following contributions give overview presentations and are of a more general character.

Technical

Dostert (1997) gives a general discussion on the history, applications, measurements, communication aspects. It is a nice overview of the state of the art of the PLC technology in 1997.
Newbury (1999) as a member of the CENELEC standardization committee reviews the evolution of using PLC, the potential problems and the development in the CENELEC standards for creating a robust medium for multiple purpose communication.
Newbury (2001) reviews the organizations in Europe involved in developing regulatory standards for PLC systems operating in the high frequency range from 1MHz to 10 MHz. Newbury starts with the reasons for standards and why it takes a long time before a standard is finalized. He continues with the two European bodies CENELEC and ETSI and their relation. It becomes clear that the interests for both groups are not identical. CENELEC has representatives from all the European countries that wish to participate in the work and the members are appointed from the national committees. ETSI is a trade organization and membership is according to the size of the company and the amount of money they pay. Two key questions require clear investigation: the level of radiation permitted and who determines the levels of emission. Any communication service in the high frequency range has an obligation not to interfere with any of the other services already present, as for instance: Military communication, Hospital services; Radio astronomy and satellite communications; Airfield navigational aids and communications; Radio amateur communications. From the presentation it is clear that many factors, including political, effects the success of high frequency power line communications.

Utilities

Electricitee de France (EDF) is using Powerline communications for a long time for management and their own transmission network. *Duval (1997)* deals with several applications investigated by EDF like: energy control; street lighting; remote service. For the remote service project a large field trial was started with 3600 terminals.
Around 1998 The Tokyo Electronic Power Company (TEPCO) was involved in several projects linking consumers and utilities for meter reading and lowering peak loading. The applicability of PLC depends on „the best solution“ from a commercial point of view that combines several techniques for access. An overview of technical access techniques was given by *Ibuki (1998)* a representative from TEPCO..
Phadke (2001) discusses defensive measures to avoid or reduce the likelihood of catastrophic failures of the power grid. Communication networks and power lines themselves play an important role in these schemes. He gives several examples of blackouts and their consequences. He further examines three different counter approaches: Adaptive relaying, which makes an automatic adjustment to protection systems so that their settings are correct for the prevailing situation; Hidden failure monitoring and control, whereby at critical substations in the power system a supervisory system is imposed on certain relays whose hidden failure and

a false trip cannot be tolerated during a system event; Special protection systems which have been designed to steer a set of protection and control actions in a direction which will reduce the probability of a disturbance turning into a catastrophic event.

Description of applications

Hosemann (1997) gives system aspects for two-way services for remote reading and control in the CENELEC band.

Business

General aspects can be found in *Linge (1999), Blackie and Brown*. They present the application of multimedia systems and telecommunications to enhance the customer service provision. The added benefits of on-line services are identified as a key marketing advantage

Ygge (2001) presents some of the major obstacles to electronic power trade, and presents promising solutions to these obstacles. In particular it is described how software agent mediated trade based on power line communication may enable medium and small size consumers and producers to trade directly from power pools, without the need of traditional energy resellers.

Broad-band powerline communications

Brown (2001) overviews the development of Broad Band powerline telecommunication access solutions. He reviews the history, market drivers, requirements and current developments. The main focus is on the optimal use of available infrastructure for access from the home and office.

Dostert (2001) analyses the possibilities and limitations of high speed indoor PLC in excess of 10Mbit/s by investigating the channel capacity with limits of unintended radiation from PLC in mind. A new approach is presented to avoid unwanted interference and achieve symmetrical coupling.

Strong (2001) concentrates on In Home PLT, and compares the emerging technology with other existing and emerging home networking technologies. This paper also includes a pragmatic view of the current European Regulatory landscape.

12. In-House Applications

PLC networking in the home can serve two goals: providing a local home network with the advantages of powerline; combine access and in-home network capabilities for service and system integration. There are several applications for a PLC network in the home: shared internet, printers, files, home control, games, distributed video, remote monitoring/security. The key asset is : “NO NEW WIRES”. Here wireless and PLC go together! Available products are in the area of: Net-connected security, safety and convenience service systems using narrow band communications.

Kaizawa (1998) and Marubayashi investigate the possible in-house applications of PLC for the Japanese market. Various ideas are classified according to their application and estimations are made on their usefulness.

The key problems in the development are: frequency management; lack of good standards; EMC (e.g. NB30, MPT1570, EN 55022...) problems; system aspects (e.g. architecture, reference model, protocol, interworking, services etc); the unavailability of devices and the role of utilities. In recent years there have been several attempts world-wide to develop home and building systems. However the different system specifications did not lead to convergence and common standards. This situation is hindering market acceptance and growth. Consequently many products or systems lack the necessary volume success.

In the US, home networking is becoming a mass market (10% over PLC. In the beginning of 2000 the HomePlug Powerline Alliance, Home Plug (http://homeplug.com/, Cisco, IBM, Texas, Intel...) started to work towards a common standard in the USA. The HomePlug Powerline Alliance is a not-for-profit corporation formed to provide a forum for the creation of open specifications for high speed home powerline networking products and services. The Chairman of the HomePlug Technical Working Group presents in *Gardner (2001)* an overview of the HomePlug standard and technology for powerline home networking.

The European Home System consortium: www.ehsa.com, defines a bus and communication protocol for communications between appliances and a central processing unit in the home. The EHS specification - EHS 1.3 - covers several medium types to transport control data, power and information, all sharing the

Logical Link Control (LLC) sub-layer. For the moment, mostly supported medium types are Power Line Carrier (230 Vac + data, 2,4 kbps, CSMA/ack, topology free) and Low Speed Twisted Pair (15 VDC, 48 kbps, CSMA/CA, topology free. *Brackmann (1997)* describes a powerline application based on the EHS standard. Also a powerline gateway solution is given to the European Installation Bus (EIB). *Sanz (2001), García Nicolás, Urriza, and Valdovinos* give the first implementation of a complete node for the EHS specifications. The node includes a microcontroller, medium access controller and a modem circuit for the EHS powerline medium specifications.

Hidalgo (2001) and Luque present the INSONET (http://www.cordis.lu/ist/projects/99-10358.htm) system consisting of an ASIC transceiver using OFDM and a protocol processor for powerline medium access control (MAC). They also discuss the status of the INSONET project: In-Home and SOHO Networking through the mains network. The INSONET project proposes an innovative technology enabling high-speed data rates over low-voltage residential power lines for in-home and SOHO networking applications, established through: - A mixed-mode ASIC in 0.35 micron CMOS technology embedding both: 1. a powerful Baseband Processor based on OFDM/16QAM advanced modulation technique and incorporating concatenated encoding / decoding system to reach an overall efficiency close to 4 bits/s/Hz 2. a complex I/Q Analog Front-End of high performances - A Protocol Processor software package implementing high-speed power line MAC layer and bridging to other existing networks, such as Ethernet and USB, in a transparent way. All devices will communicate with each other over an IEEE 1394 data backbone.

The following contributions are not within a major consortium, but give an interesting overview of the individual activities.

Downey (1997) gives a hybrid power line/twisted pair architecture for central control in commercial buildings. The twisted pair is used as a backbone for power line routers to bypass primary side power wiring and to reach troublesome nodes. He also describes the fact that communications on a power line is generally asymmetrical.

Brown (2001) describes a Desk-top Area Network (DAN) for the interconnection of personal computer peripherals. The radius of operation is 2 meter with 2 or more ports within the frequency range from 3 to 30 Mhz.

Dalichau (2001) evaluates the different frequency bands regarding their qualifications for in-house powerline communications. He describes the properties and the possible applications of high speed (2.5 Mbit/s) PLC-modems using frequencies up to 525 kHz.

Shimizu (1998), Genji, Sakagami, Toda, and Horino compare Frequency Shift keying and Spread Spectrum modulation for a load control system for Japanese environments and conditions. The SS system was preferred for circumstances where many air condition systems are present.

13. Miscellaneous

Griepentrog (2001) describe the characteristics of DC-networks, which need to be considered with regard to the implementation of PLC. Focus is on the 750 V DC-networks, which usually are found in local transportation systems, i.e., tram or underground traction power systems. Adaptive OFDM within the CENELEC-band (10 to 150 kHz) is assumed. Characteristics such as typical disturbances and harmonics, as well as access impedance and signal attenuation are considered, and test results are reported.

Römer (2001) reports from a project aiming to demonstrate the integrated functioning of all dwelling control systems and the possibility of additional energy conservation. A home network based on Echelon Lonworks PLC is used. The focus of this paper is on the systems present in the building, which must be regulated and controlled.

de Cogan (2000) and Tavner summarizes the evolution of a communication-over-the-mains student project at the University of East Anglia, Norwich.

14. References

ISPLC 1997 – 2001 Contributions used in this Summary

1. Measurements, Models, Channel Transfer Characterization

Low frequency range

O. Hooijen (1997), Universität Essen, Germany*, A Channel Model for the Low-Voltage Power-Line Channel*

M. Arzberger (1997), K. Dostert, T. Waldeck, and M. Zimmermann, University of Karlsruhe, Germany, *Fundamental Properties of the Low Voltage Power Distribution Grid.*

S. Ramseier (1998), B. Sabbattini, and Ch. Imboden, ABB Corporate Research Ltd., Switzerland, ABB Network Partner AG, Switzerland, *A Novel Method for Measuring the Characteristics of the Powerline Channel for High Speed Communications.*

P. Moreau (1999) and M. Rousseau, Schlumberger Industries-MTC, France, *Characterisation of PLC Technologies.*

E. Yavuz (2000), F. Kural, N. Çoban, B. Ercan, and M. Şafak, Hacettepe University, Turkey, Başari Elektronik A.Ş., Turkey, *Modelling of Power-Lines for Digital Communications.*

High frequency range

K. Dostert (1998), University of Karlsruhe, Germany, *RF-Models of the Electrical Power Distribution Grid.*

H. Philipps (1998), Braunschweig Technical University, Germany, *Performance Measurements of Powerline Channels at High Frequencies.*

H. Philipps (1999), Institute for Communications Technology, Braunschweig, Germany, *Modelling of Powerline Communication Channels.*

A. Voglgsang (2000), T. Langguth, G. Körner, H. Steckenbiller, and R. Knorr, Fraunhofer Einrichtung für Systeme der Kommunikationstechnik, Germany, *Measurement Characterization and Simulation of Noise on Power-Line Channels.*

H. Philipps (2000), Braunschweig Technical University, Germany, *Development of a Statistical Model for Power-Line Communication Channels.*

M. Zimmermann (2000) and K. Dostert, University of Karlsruhe, Germany, *An Analysis of the Broadband Noise Scenario in Power-Line Networks.*

N. González-Prelcic (2001), C. Mosquera, N. Degara, and A. Currais, Universidad de Vigo, Spain*, A Channel Model for the Galician Low Voltage Mains Network.*

J. Yazdani (2001), M. Naderi, and B. Honary, Lancaster University, UK, *Power Lines Analysing Tool (PLAT) for Channel Modelling.*

T. V. Prasad (2001), S. Srikanth, C. N. Krishnan, and P. V. Ramakrishna, Anna University, India, *Wideband Characterization of Low Voltage outdoor Power Line Communication Channels in India.*

S. Tsuzuki (2001), S. Yamamoto, T. Takamatsu, and Y. Yamada, Ehime University, Japan, *Measurement of Japanese Indoor Power-line Channel.*

F. J. Cañete Corripio (2001), L. Díez del Rio,, and J. T. Entrambasaguas Muñoz, Universidad de Málaga, Spain, *A Time Variant Model for Indoor Power-Line Channels.*

P. Corlay (2001), F. X. Coudoux, M. Gazalet, F. Ruolt, and F. Haine, Université de Valenciennes, France, *An efficient modelling of the impulse response of the indoor power line communication channels in high frequencies range.*

C. Assimakopoulos (2001) and F.-N. Pavlidou, Aristotle University of Thessaloniki, Greece, *Measurement and Modeling of In-House Power Lines Installation for Broadband Communications.*

J.-h. Lee (2001), J.-h. Park, H.-S. Lee, G.-W. Lee, and S.-c. Kim, LG Electronics, Korea, Keyin Telecom, Korea, Seoul National University, Korea, *Measurement, Modeling and Simulation of Power Line Channel for Indoor High-speed Data Communications.*

Noise analysis

G. Marubayashi (1997), Soka University, Japan, *Noise Measurements of the Residential Powerline.*

K. Moriyama (1998), H. Kubota, and K. Sakaniwa, Tokyo Institute of Technology, Japan, Chiba Institute of Technology, Japan, *Generative Mechanism of Harmonic Noise and Periodic Signal Fading and its Model in Power line communication.*

O. Ohno (1998), M. Katayama, T. Yamazato, and A. Ogawa, Nagoya University, Japan, *A Simple Model of Cyclostationary Power-line Noise for Communication Systems.*

M. Katayama (2000), S. Itou, T. Yamazato, and A. Ogawa, Nagoya University, Japan, *Modeling of Cyclostationary and Frequency Dependent Power-Line Channels for Communications.*

Analysing and simulation tools

G. Bumiller (1999), iAD GmbH, Großhabersdorf, Germany, *Power-Line Analysing Tool for Channel Estimation, Channel Emulation and Evaluation of Communication Systems.*

H. Philipps (2001), Braunschweig Technical University, Germany, *A Hardware Fading Simulator for Powerline Communication Channels.*

M. Sebeck (2001) and G. Bumiller, iAd GmbH, Germany, *Power-Line Analysing Tool for Channel Estimation, Channel Emulation and Noise Characterisation.*

E. Yavuz (2001) and M. Şafak, Hacettepe University, Turkey, *Realization of Simulation Software for Power Line Communications. .*

Channel capacity estimations

O. G. Hooijen, (1998) and A.J. H. Vinck, Signal Communications, University of Essen, Germany, *On The Channel Capacity of A European-Style Residential Power Circuit.*

F. J. Cañete (2000), L. Díez, and J. T. Entrambasaguas, Universidad de Málaga, Spain, *Indoor Power-Line communications: Channel Modelling and Measurements.*

T. Esmailian (2000), F. R. Kschischang , and P. G. Gulak, University of Toronto, Canada, *Characteristics of In-building Power Lines at High Frequencies and their Channel Capacity.*

P. J. Langfeld (2001), University of Karlsruhe, Germany, *The Capacity of typical Powerline Reference Channels and Strategies for System Design.*

2. Cable and Network Characterization

Low frequency range

A. B. Dalby (1997), Technical University of Denmark, *Signal Transmission on Power-Lines; Analysis of power-line circuits.*

O. G. Hooijen (1998), University of Essen, Germany, *On The Relation Between Network-Topology and Power Line Signal Attenuation.*

G. Duval (1998), Electricite de France (EDF), France, *Low Voltage Network Models to the Analysis of Unexpected Phenomena in PLC Communications.*

D. Chaffanjon (1998), Electricite de France (EDF), France *A Real Knowledge of Propagation: the Way of Efficiency and Reliability Making PLC Generalization Feasible.*

J. S. Barnes (1998), Central Queensland University, Australia, *A Physical Multi-Path Model for Power Distribution Network Propagation.*

C. Hannaford (2000) and C. Davies, Lancaster University, UK, ATG Ltd., *High-frequency Signal Loss in Power Line Current Loops.*

High frequency range

P. Brown (1997), Norweb Communications, UK, *Directional Coupling of High Frequency Signals onto Power Networks.*

J. Dickinson (1997) and P. Nicholson, Norweb Communications, UK, *Calculating the High Frequency Transmission Line Parameters of Power Cables.*

M. Zimmermann (1999) and K. Dostert, University of Karlsruhe, Germany, *A Multi-Path Signal Propagation Model for the Power Line Channel in the High Frequency Range.*

C. Hensen (1999), W. Schulz, S. Schwarze, E. Borchers, and G. Dickmann, University of Paderborn, Germany, ke Kommunikations-Elektronik GmbH, Germany, *Characterisation, Measurement and Modelling of Medium Voltage Power-Line Cables for High Data Rate Communication.*
A. Matov (2001), Swiss Federal Institute of Technology Lausanne, Switzerland, *A Planning Tool for High Bit Rate Transmission Over Power Line Communication Channel.*
Th. Sartenaer (2001) and P. Delogne, Université catholique de Louvain, Belgium, *Powerline cables modelling for broadband communications.*
T. C. Banwell (2001) and S. Galli, Telcordia Technologies, Inc., USA, *On the Symmetry of the Power Line Channel.*
T. C. Banwell (2001) and S. Galli, Telcordia Technologies, Inc., USA, *A New Approach to the Modeling of the Transfer Function of the Power Line Channel.*

3. Coding and Modulation Techniques

Communication channel model

P. A. Brown (1998), NORWEB Communications, UK, *Some Key Factors Influencing Data Transmission Rates in the Power Line Environment When Utilising Carrier Frequencies Above l MHz.*
R.P. Rickard (2000), Nortel Networks, UK, *A Practical Realisation of a PLC Modem System: Design Aims and Results.*

Techniques

M. Sekizawa (1998), Y. Yahagi, H. Hasegawa, and Y. Kamitaira, Tohoku Electric Power Co., Inc., Osaki Electric Co., Ltd., *Development of High Speed Communication System Using Power Distribution Line Carrier.*
D. Lund (1999), B. Honary, and M. Darnell, HW Communications Ltd, UK, *Adaptive Nested Codec.*
L. Lampe (1999) and R. Fischer, Universität Erlangen-Nurnberg, Germany, *Comparison and Optimization of Differentially Encoded Transmission on Fading Channels.*
G. Lindell (1999) and L. Selander, University of Lund, Sweden, *On Coding-, Diversity- and Receiver Strategies for the Powerline Communication Channel.*
P. Chippendale (2000), B. Honary, and M. Scott, Lancaster University, UK, DERA, Portsdown, UK, *Adaptive Frequency Allocation for Powerline Transmission.*
B. Baumgartner (2000), H. Griesser, and M. Bossert, University of Ulm, Germany*, On Iterative Multistage Decoding of Multilevel Codes for Frequency Selective Channels.*
A.J. H. Vinck (2000) and J. Häring, University of Essen, Germany, *Coding and Modulation of Power-Line Communications.*
G. Lindell (2000), Lund University, Sweden, *On Coding and Modulation for the Power-Line Communication Channel* .
T. Hesse (2001) and W. Schulz, University of Paderborn, Germany, *Blind Adaptive Multi-User Detection Applied to a Power-Line Data Transmission System.*
D. Umehara (2001), M. Kawai, and Y. Morihiro, Kyoto University, Japan, *Performance Analysis of Noncoherent Coded Modulation for Power Line Communications.*
J. Häring (2001) and A.J. H. Vinck, University of Essen, Germany, *Coding for Impulsive noise Channels.*

Discrete multi-tone modulation

F. Petré (1999), M. Engels, B. Gyselinckx, and H. De Man, Interuniversity Micro Electronics Centre, Heverlee, Belgium, *DMT-Based Power Line Communication for the CENELEC A-Band.*
T. Sartenaer (2000), F. Horlin, and L. Vandendorpe, Université Catholique de Louvain, Belgium, *DMT-FDMA as a Multiple Access Technique for Wideband Upstream Power-Line Communications.*
G. Pay (2001) and M. Şafak, Hacettepe University, Turkey, *Performance of DMT Systems under Impulsive Noise.*
M. Rousseau (2001), P. Moreau, and M. Bellanger, Montrouge Technology Center and CNAM, France, *Characterization and optimization of multicarrier technologies over PLC channel.*

4. Modem Design

Based on FSK

M. Görlitz (1997), Görlitz Computerbau GmbH, Germany, *The Enercom network for PLC applications.*
G. Telkamp (1997), ATICON, Germany, *A low cost Power-Line Node for Domestic Applications.*

Based on SFSK

B. Goffart (1997), G.Evens, P. Desneux, and J. Boxho, Alcatel Mietec, Belgium, *An Integrated PLC modem circuit for S-FSK modulation.*
B. Goffart (1999) and C. Boscand, Alcatel Microelectronics, Belgium, *An Integrated PLC Modem for S-FSK Modulation.*

Based on OFDM

M. Deinzer (1999) and M. Stöger, iAd GmbH, Großhabersdorf, Germany, *Integrated PLC-Modem based on OFDM.*
D. Galda (1999), T. Giebel, U. Zölzer, and H. Rohling, Technical University of Hamburg, Germany, *An Experimental OFDM-Modem for the CENELEC B-Band.*
H. Dalichau (2000) and W. Täger, Polytrax Information Technology AG, Germany, *Description of the Technology and Comparison of the Performance of Two Different Approaches for a Power-Line Modem in the CENELEC-Band.*
G. Bumiller (2001) and M. Sebeck, iAd GmbH, Germany, *Complete Power-Line Narrow Band System for Urban-Wide Communication.*

Based on DS/SS

D. Raphaeli (2000) and A. Grauer, ITRAN Communications Ltd., Israel, *A New Power-Line Communications Modem Based on a Novel Modulation Technique.*

Based on DMT

B. Kaplan-Güvenç (2001), N. Çoban, and M. Şafak, Başari Elektronik A.Ş., Turkey, Hacettepe University, Turkey, *A DSP Based DMT Modem for Power Line Communications.*

General aspects

H. Beikirch (2000) and M. Voß, University of Rostock, Germany, *CAN-Transceiver for field bus powerline communications.*

5. OFDM

Performance analysis

S. Nomura (2001), T. Shirai, M. Itami, and K. Itoh, Science University of Tokyo, Japan, *A Study on Controlling Transmission Power of Carriers of OFDM Signal.*
L. H. J. Lampe (2000), R. F. H. Fisher, and R. Schober, University Erlangen-Nürnberg, Germany, *Performance Evaluation of Non-Coherent Transmission over Power-Lines.*
K. Sugimoto (2001), M. Katayama, T. Yamazato, and H. Okada, Nagoya University, Japan, *Performance of an OFDM Communication System under a Frequency and Time Dependent Power-Line Channel.*
J. Häring (2000) and A.J. H. Vinck, University of Essen, Germany, *OFDM Transmission Corrupted by Impulsive Noise.*
V. Dégardin (2001), M. Liénard, P. Degauque, A. Zeddam, and F. Gauthier, Université des Sciences et Technolgies de Lille, France, France Telecom R&D, France, *OFDM Transmission Corrupted by Colored and Narrow Band Noise.*
D. Galda (2001) and H. Rohling, Technical University of Hamburg-Harburg, Germany*, Narrow Band Interference Reduction in OFDM-based Power Line Communication Systems.*
P. J. Langfeld (2000) and K. Dostert, University of Karlsruhe, Germany, *OFDM System Synchronization for Power-Line Communications.*

J. Yazdani (2000), M. Mufti, P. Brown, and B. Honary, Lancaster University, UK, *Modelling of an OFDM Transmission Technique for Power-Line using UNIX based "COSSAP" and Power-Line Channel Simulator.*
A.G. Burr (1999) and P. A. Brown, *Application of OFDM to Powerline Telecommunication***.**

Comparison with other techniques
W. Schulz (2000) and S. Schwarze, University of Paderborn, Germany, *Comparison of CDMA and OFDM for Data Communications on the Medium Voltage Power Grid.*
D. Raphaeli (1999) and E. Bassin, Tel Aviv University, Israel, Itran Communications, Israel, *A Comparison Between OFDM, Single Carrier, and Spread Spectrum for high Data Rate PLC.*

6. Spread Spectrum Techniques

General aspects
P.W. Baier (1998), Univ. of Kaiserslautern, Germany, *Spreading Techniques and Applications.*
P. Sutterlin (1998), Echelon Corporation, USA, *A Power Line Communication Tutorial - Challenges and Technologies.*
S. Burley (1999) and M. Darnell, Leeds University, UK, *Non-Gaussian Noise Suppression and its Application to Power-Line Communications.*

Frequency hopping spread spectrum (FH)
K. Fallows (1998), J. Yazdani, P. Brown, and B Honary, Lancaster University, England UK, NORWEB Communications, England UK, *Data protection and transmission over low voltage in-house power line channel.*
G. Marubayashi (1999), Soka University, Japan, *A Novel High Capacity Frequency Hopping Spread Spectrum System Suited to Power Line Communications.*
N. Ishikawa (2000) and G. Marubayashi, Soka University, Japan, *Studies on FH/MMFSK Power-Line Transmission System.*
M. Hamamura (2001) and G. Marubayashi, Kochi University of Technology, Japan, SOKA University, Japan, *Parallel MMFSK modulation system - A novel frequency hopping system for power-line communications -.*

Sequences for spread spectrum applications
S. Tsuzuki (1997), S. Yoshida, S. Tazaki, and Y. Yamada, Ehime University, Japan, Kyoto University, Japan, *A Class of Partial Response Spread M Sequence and its Correlation Property.*
N. Suehiro (1998), T. Imoto, and A.J. H. Vinck, University of Tsukaba, Japan, Soka University, Japan, University of Essen, Germany, *Cellular Powerline CDMA Communication without Co-Channel Interference.*
S. Sasaki (1997) and G. Marubayashi, Niigata University, Japan, Soka University, Japan, *Parallel Combinatorial Spread Spectrum Communication Systems over Residential Power-line.*
S. Tachikawa (1998) and H. Inamura, Nagaoka University, Japan, Tohoku Electric Power Co., Japan, *Simplified Correlation Mapping in M-ARY/SS System and its Application for Power Line.*
E. Del Re (2000), R. Fantacci, S. Morosi, R. Seravalle, and G. Pieraccioli, Università di Firenze, Italy, *Orthogonal Direct Sequence Code Division Multiple Access for Broadcast Communications on Power-Lines.*
E. Del Re, (2001), R. Fantacci, S. Morosi, and R. Seravalle, Università degli studi di Firenze, Italy, *Comparison of CDMA and OFDM systems for Broadband Downstream Communications on Low Voltage Power Grid.*
N. Pem (1999) and M. Darnell, Leeds University, UK, *OFDM Using Complementary Sequences for Data Transmission Over Non-Gaussian Channels.*

Communication system aspects
C. Hensen (1998) and W. Schulz, University of Paderborn, Germany , *BER Measurements in a High Data Rate DS-CDMA System for Power Line Applications.*
C. Hensen (1999) and W. Schulz, University of Paderborn, Germany, *ISDN-So-Bus Extension by Power-Line Using CDMA Technique.*

C. Hensen (2000) and W. Schulz, University of Paderborn, Germany, *Hardware Design of a Multi-User DS-CDMA Processor for Power-Line Communications.*
S.-J. Lee (2001), M.-G. Kim, J.-H. Oh, K.-D. Kim, and G.-W. Lee, Kookmin University, Korea, Keyin Telecom., Ltd., Korea, *On the Digital Design with FPGA for Power Line Voice-Modem Using the MC DS-CDMA.*
Y. Kanamori (1998), S. Nishimura, M. Takashima, Y. Asuka, M. Wada, and A. Shimodaira, Kansai Electric Power Co., Inc., Japan, Matsushita Electric Industrial Co., Ltd., Japan, *Development of a Spread Spectrum Transmission System for Low-Voltage Distribution Lines.*
H. Kusaka (1997), M. Kominami, S. Ikuta, and T. Arimura, Osaka Sangyo University, Japan, Osaka Prefecture University, Japan, Sharp Corporation, Japan, *Performance of DS-SSMA Systems with Narrow-band Interference Rejection Filters Using Band-limited Power-lines.*
D. Radford (1997), Intellon Corporation, USA*, Spread Spectrum Technology enables reliable Low Cost Communications on the Powerline.*

7. Hardware

C. Romero Pérez (2000), R&TD Group of Sainco, Spain, *ADAPT: An Automatic Impedance Adapter for Medium-Voltage Communications Equipment.*
G. Bumiller (2001) and M. Deinzer, iAd GmbH, Germany, *Narrow Band Power-Line Chipset for Telecommunication and Internet Application.*
A. Ghazel (2001) and F. Rouissi, Ecole Supérieure des Communications de Tunis, Tunisia, *Efficient low-cost DSP-based Hardware Architecture for Power Line Communications*.

8. Protocols

Data link and medium access protocols

M. Mufti (2000), J. Yazdani, P. Brown, and B. Honary , Lancaster University, UK, *Data Link Layer protocol for a Powerline Local Area Network.*
M. Propp (2000), Adaptive Networks, Inc., USA, *The Power-Line as a Reliable Multimedia-Capable Home Network.*
T. Coffey (1998), J. Griffin and B. Moore, *A media access control protocol for a power-line local area network.*
H. Hrasnica (2001), A. Haidine, and R. Lehnert, Dresden University of Technology, Germany, *Reservation MAC Protocols for Powerline Communications.*
S. Tsuzuki (2000) and Y. Yamada, Ehime University, Japan, *Utilization and Delay Performance Analysis of Carrier Sense CDMA Protocol.*
T. Langguth (2000), R. Steffen, M. Zeller, H. Steckenbiller, and R. Knorr, Fraunhofer Institute for Communication Systems, Germany, *Performance Study of Access Control in Power Line Communication*.
M. Stantcheva (2000), K. Begain, H. Hrasnica, and R. Lehnert, Dresden University of Technology, Germany, *Suitable MAC Protocols for an OFDM Based PLC Network*.
L. H.-J. Lampe (2001), Universität Erlangen-Nürnberg, Germany, *Medium Access Scheme for TDMA.*
M. Mushkin (2001), ITRAN Communications Ltd, Israel*, A Novel Distributed Synchronized Media Access Control Mechanism and its Applicability to In-House Power-Line Networking*.

Network layer

B. Gallagher (2000), B. Moore, and T. Coffey, Altcom Limited, Ireland, University of Limerick, Ireland, *A Transport Protocol Independent Driver for a power-line local area network.*
M. Sebeck (2000) and G. Bumiller, iAd GmbH, Germany, *A Network Managment System for Power-Line Communications and its Verification by Simulation.*
G. Bumiller (2001), iAd GmbH, Germany, *Network Management System for Telecommunication and Internet Application.*
M. Ostertag (1998) and C. Imboden, ABB Corporate Research Ltd., Switzerland, ABB Network Partner AG, Switzerland, *A High Data Rate Powerline Communication System for Combined DA/DSM.*

Application layer
T. Somogyi (1997), Schlumberger, France, *DLMS – the Application Protocol for communication meters.*

Data security
T. Newe (2000) and T. Coffey, University of Limerick, Ireland, *Verifying a Minimum - Knowledge Authentication Protocol for use with Power Line Networks.*
R. Dojen (2001) and T. Coffey, University of Limerick, Ireland, *On the Cryptographic Strength of Symmetric Ciphers Suitable for Power-Line Communications.*

9. Standards

Bodies and their tasks
P. Fuchs (1997), Convenor IEC TC13, WG14, I*ntegration through Standardisation.*
M. Harris (1999*),* OTEL, UK*, Power Line Communications - A Regulatory Perspective.*

Comparisons with standards
T. Giebel (2000) and H. Rohling, Technical University of Hamburg-Harburg, Germany, *Regularity Aspects of OFDM Based Power-Line Applications.*
D. Heffernan (2000) and D. P. Burton, University of Limerick, Ireland*, Proposal for a Fieldbus Standard to Support European Power-Line Communications.*

Radiated emission
D. Lauder (1999) and Y. Sun, University of Hertfordshire, UK, *Modelling and Measurement of Radiated Emission Characteristics of Power Line Communications Systems for Standards Development.*
R. Vick (2001) EMV – Beratungs- und Planungsbüro, Germany, *Radiated Emission caused by In-House PLC-Systems.*
D. Fenton (2001) and P. Brown, White Box Solutions Ltd., UK*, Some Aspects of Benchmarking High Frequency Radiated Emissions from Wireline Communication Systems in the Near and Far Fields.*
R. P. Rickard (1999) and J.E. James, Nor.web DPL Ltd/Nortel Networks, Harlow Laboratories, *A Pragmatic Approach to Setting Limits to Radiation from Powerline Communications Systems.*
S. Roper (2001), nSine Ltd., UK, *Some Issues in the Near and Far Field Radiated Emission Benchmarking of PLT Systems.*
C. Hensen (2001) and S. Schwarze, Intellon Design Center Europe GmbH, Germany, University of Paderborn, Germany, *Electromagnetic Compatibility for Power-Line Communications on the Medium Voltage Power Grid.*
F. Issa (2001), D. Chaffanjon, and A. Pacaud, Electricité de France, France, Ecole Supérieure d'Electricité, France, *Radiated Emission Associated with Power Line Communications on Low Voltage Buried Cable.*
P.A. Brown (2000), J. Yazdani, and B. Honary, White Box Solutions, UK, Lancaster University, UK, *Criteria for a Coexistence Algorithm for Wireline Access Technologies. .*
A. G. Burr (1998), D. M. W. Reed, and P. A. Brown, University of York, UK, NORWEB Communications, UK, *HF Broadcast Interference on LV Mains Distribution Networks.*
J. Yazdani (1999), P. Brown, and B. Honary, Lancaster University, UK, NOR.WEB DPL Ltd., UK, *Powerline in-house near and far field propagation Measurements.*
M. Gebhardt (2001), University of Karlsruhe, Germany, *Characteristics of the Magnetic Field emitted by a Residential Building Supplied with PLC.*

10. Field Trials

E. Wenker (1997) and W. R. Härry, Stadtwerke Düsseldorf AG, Germany, Landis & Gyr Corp., Switzerland, *Demand Side Management using DLC Communication.*
M. Propp (1997), Adaptive Networks Inc., USA, *The Use of Reliable Powerline Communications in Telemanagement Trials.*
P. Chudi (2001), Graninge AB, Sweden, *Experiences from PLC field trial and business model.*

R. Kamphuis (2001), C. Warmer, and H. Akkermans, Netherlands Energy Research Foundation ECN, The Netherlands, Free University Amsterdam VUA, The Netherlands, *SMART:Innovative e-Services for Smart Buildings.*

11. Overview

<u>Technical</u>

K. Dostert (1997), University of Karlsruhe, Germany, *Telecommunications over the Power Distribution Grid; Possibilities and Limitations.*
J. Newbury (1999), The Open University, UK, *Technical Developments in Powerline Communications.*
J. E. Newbury (2001), The Open University, England, *Regulatory Requirements for Power Communication Systems operating in the High frequency band.*

<u>Utilities</u>

G. Duval (1997), Electricite de France (EdF), France, *Applications of PLC at Electricite de France.*
J. Ibuki (1998), Tokyo Electric Power Company, Japan, *Power Line Communication in Japan.*
A. G. Phadke (2001), Virginia Tech, USA, *Power Line Communication for Defence against Catastrophic Failures of Complex Interactive Power Networks.*

<u>Description of applications</u>

A. Hosemann (1997), Siemens, Germany*, PLC Applications in Low Voltage Distribution Networks.*

<u>Business</u>

N. Linge (1999), N. M. Blackie, and P. Brown, University of Salford, UK, NOR.WEB, *Interactive On-Line Customer Service Applications for Delivery over Power Line Infrastructures.*
F. Ygge (2001), EnerSearch AB, Sweden, *Power Line Communication as a Means for Electronic Power Markets.*

<u>Broad-band powerline communications</u>

P. Brown (2001), White Box Solutions Ltd, UK, *Broad Band PLT Access Solutions - Assessing Developments.*
K. Dostert (2001), University of Karlsruhe, Germany, *New PLC Approaches for High Speed Indoor Digital Networks.*
P. Strong (2001), nSine Limited, UK, *Regulatory & Consumer Acceptance of Powerline Products.*

12. In-House Applications

Y. Kaizawa (1998) and G. Marubayashi, Soka University, Japan, *Needs for the Power Line Communications.*
S. Gardner (2001), Conexant Systems, Inc., *The HomePlug Standard for PowerLine Home Networking.*
L. Brackmann (1997), ATICON, Germany, *Power line applications with European Home Systems.*
A. Sanz (2001), J. I. García Nicolás, I. Urriza, and A. Valdovinos, University of Zaragoza, Spain, *A Complete Node for the Power Line medium of European Home Systems Specifications.*
A. Hidalgo (2001) and A. Luque, Sainco, Spain, *INSONET - In-Home and SoHo Networking through the Mains Network.*
W. Downey (1997), Echelon, USA, *Central Control and Monitoring in Commercial Buildings using PLC.*
P. Brown (2001), White Box Solutions Ltd., UK, *DAN's a Cellular Approach to Broadband In-House Power Line Communications.*
H. Dalichau (2001), PolyTrax Information Technology AG, Germany, *Evaluation of Different Frequency Bands Regarding their Qualification for Inhouse Powerline Communication.*
K. Shimizu (1998), T. Genji, K. Sakagami, K. Toda, and H. Horino, Kansai Electric Power Co., Inc., Japan, Matsushita Electric Industrial Co., Ltd., Japan, Tokoseiki Co., Ltd., Japan, *Application of Power Line Communication with FSK and SS for DSM System.*

13. Miscellaneous

G. Griepentrog (2001), Siemens AG Erlangen, Germany, *Powerline Communication on 750 V DC Networks.*

J. C. Römer (2001), Netherlands Energy Research Foundation ECN, The Netherlands, *Demand Controlled Ventilation in a Low-Energy House for Energy Conservation Using Power Line Communication Technique as Home Network.*

D. de Cogan (2000) and P. J. Tavner, University of East Anglia, UK, *Over-the-mains Communications Projects at the University of East Anglia.*

Proceedings

Proceedings 1997 International Symposium on Power-Line Communications and its Applications, 2nd Edition, April 2-4, 1997, Essen, Germany, Editors Olaf Hooijen and A J. Han Vinck, ISBN 90-74249-16-7.

Proceedings 1998 International Symposium on Power-line Communications and its Applications, March 24-26, 1998, Soka University, Tokyo, Japan, Editors Gen Marubayashi and A.J.Han Vinck, ISBN 90-74249-18-3.

Proceedings of the 3rd International Symposium on Power-Line Communications and its Applications (ISPLC'99), Lancaster, UK, 1999, Editors Bahram Honary and A.J. Han Vinck, ISBN 90-74249-22-1.

2000 International Symposium on Power-line Communications and its Applications (ISPLC2000) Limerick, Ireland , April 5-7, 2000, Editors T. Coffey and S. McGrath, ISBN 1-87 4653-60-7.

Proceedings of the 5th International Symposium on Power-Line Communications and its Applications (ISPLC'01), Malmö, Sweden, 2001, Editors S. Höst and L. Månsson, ISBN: 91-7167-021-1.

Proceedings IEEE Fourth International Symposium on Spread Spectrum Systems and Applications, Mainz 1996, ISBN 0-7803-3567-8.

Proceedings 2000 International Zurich Seminar on Broadband Communications,
Zurich, Switzerland, February 2000.

Documents

EN 50065-1: Signalling on Low Voltage Electrical Installations in the Frequency Range 3kHz to 148.5 kHz., CENELEC, Brussels, 1991.

IEC 61334-5-4 Ed. 1.0: Distribution Automation Using Distribution Line Carrier Systems-Part 5: Lower Layer Profiles –Section 4: Multicarrier Modulation Profile, 1997.

EHSA, "European Home Systems Specification", release 1.3, EHSA Zavenem, Belgium, March 1997.

ETSI Systems Reference Document; Broadband Powerline Communications; Workitem V1.5; 2000-06, http://www.etsi.fr

Journals

Special Issue on Powerline Communications, Archiv für Elektronik und Übertragungstechnik (International Journal of Electronics), January 2000.

M. D'Amore, M. Sarto, "Electromagnetic Field Radiated from a Broadband Signal Transmission on Power line Carrier Channels," IEEE Tr. on Power Delivery, April 1997.

M. D'Amore, M. Sarto, "Digital Transmission Performance of Carrier Channels on Distribution Power Line Networks," IEEE Tr. on Power Delivery, April 1997.

M. Chan and R. Donaldson, "Amplitude, Width and Interarrival Distribution for Noise Impulses on Intrabuilding Power Line Communication Networks," IEEE Trans. on EMC, pp. 320-323, August 1989.

M. Chan and R. Donaldson, " Attenuation of Communication Signals on Residential and Commercial Intrabuilding Power-Distribution Circuits," IEEE Trans. on EMC, pp. 220-230, Nov. 1986.

M. Chan, D. Friedman, R. Donaldson, "Performance enhancement using forward error correction on power line communication channels", IEEE Tr. on Power Delivery, Vol: 9 2, pp. 645-653, April 1994.

K. Dostert, "All Digital Spread Spectrum Modems for PLC", European Trans. on Telecommunications, ETT, pp. 507-514, 1996.

K. Dostert, "Fundamental Properties of the Low Voltage Power Distribution Grid Used as a Data Channel", European Transactions on Telecommunications, ETT, Vol. 11, No. 3 May/June 2000, pp. 297-306.

H. Dorey, "Remote Metering-How not to replace the meter reader," Electronics and Power, pp. 163-165, February 1983.

K. Endo, T. Nakamura, S. Tsumura, and S. Tsuruta, “Spread Spectrum Communication Method for Powerline,“ Trans. IEICE, pp. 234-243, May 1991.
H. Ferreira, H. Grove, O. Hooijen and A. Han Vinck, “Power Line Communication,” Wiley Encyclopedia of Electrical and Electronics Engineering, pp. 706-715.
M. Forti and L. Millanta, “Power Line Impedance and the Origin of the Low-Frequency Oscillatory Transients,” IEEE Trans. on EMC, 87-97, 1990.
R. Gerson, D. Propp, and M. Propp, “A Token Pasing Network for Powerline Communications,” IEEE Tr. on Consumer Electronics,” May 1991.
P. Van der Gracht and R. Donaldson, “Communication Using Pseudonoise Modulation on Electric Power Distribution Circuits,” IEEE Tr. on Comm. 964-974, 1985.
W. Hagman, “Spread Spectrum Communications for Load Management,” IEEE Tr. on Power Delivery, pp. 75-81, January 1989.
O. Hooijen, "Channel Model for the Residential Power Circuit used as a Digital Communications Medium,” IEEE Trans. on EMC, vol. 40, no. 4, pp. 331-336, November 1998.
O. Hooijen, "On the Channel Capacity of the Residential Power Circuit used as a Digital Communication Medium,” IEEE Comm. Letters, pp. 267-268, October 1998.
R. Kohno, H. Imai, M. Hatori, and S. Pasupathy, “An Adaptive Canceller of Cochannel Interference for Spread Spectrum Multiple Acces Communication Networks in a Power Line,” IEEE Jounal on Selected Areas in Communications, pp. 691-699, May 1990.
D. Liu, E. Flint, B. Gaucher, and Y. Kwark, “Wide Band AC Power Line Characterization,” IEEE Trans. on Consumer Electronics,” pp. 1087-1097, Nov. 1999.
R. Madge, G. Hatanaka, “Power Line Carrier Emission from Transmission Lines,” IEEE Tr. on PWRD, October 1992.
J. Malack and J. Engstrom,”RF Impedance of US and European Power Lines,” IEEE Trans. on EMC, 36-38, 1976.
Masaoki and Tanaka, “High Frequency Noise Power Spectrum, Impedance and Transmission Loss of Power Line Communications,” IEEE Trans. on Consumer Electronics, pp. 321-326, May 1998.
J. Naredo, J. Silva, R. Romero, and P. Morena, “Application of Appriximate Model Analysis Methods for PLC Systems Design,” IEEE Trans. on Power Delivery, Jan 1987.
J.B. O’ Neal Jr, “The Residential Power Circuit as a Communication Medium,“ IEEE Trans. on Consumer Electronics, pp. 567-577, August 1986.
J.B. O’Neal Jr, “Substation Noise at Distribution Line Communication Frequencies,” IEEE Trans. on EMC, 71-77, 1988.
J. Newbury, “Communication Requirements and Standards for Low Voltage Mains Signaling,” IEEE Trans. on Power Delivery, January 1998.
J. Nicholson and J. Malack, “RF Impedance of Power Lines and Line Impedance Stabilization Network in Conducted Interference Measurement,” IEEE Trans. on EMC, pp. 84-86, May 1973.
H. Niwa, O. Ohno, M. Katayama, T. Yamazato, and A. Ogawa, “A Spread spectrum System with Dual Processing Gains Designed for Cyclic Noise in PLC,” IEICE Fundamentals, pp. 2526-2533, Dec. 1997.
J. Onunga and R. Donaldson, “Personal Computer Communications on Intrabuilding Power Line LAN’s Using CSMA with Priority Acknowledgements,” IEEE Journal on Selected Areas in Communications, pp. 180-191, November 1989.
J. Onunga, R. Donaldson, “A simple packet retransmission strategy for throughput and delay enhancement on power line communication channels”, IEEE Tr. on Power Delivery, Vol: 8 3, pp. 818-826, July 1993.
Power Systems Communications Committee, Summary of an IEEE Guide for Powerline Carrier Applications, IEEE Tr. Power Apparatus Syst., 2334-2337, 1980.
D. Radford, “Spread Spectrum Data Leap Through AC Power Wiring,” IEEE Spectrum, pp. 48-53, November 1996.
B. Russell, “Communication Alternative for Distribution Metering and Load Management,” IEEE Tr. Power Apparatus and Systems, pp. 1448-1455, July/Aug. 1980.
T. Schaub, “Spread Frequency Shift Keying,” IEEE Trans. on Comm., pp. 1056-1064, 1994.
A. Smith Jr., “The Residential Power Circuit as a Communication Medium,” IEEE Tr. on EMC, pp. 31-32, Febr. 1972.
M. Shwehdi, A. Khan, “A power line data communication interface using spread spectrum technology in home automation”, IEEE Tr. on Power Delivery, Vol: 11 3, pp. 1232-1237, July 1996.

J. Suh et al., “Measurement of Communication Signal Propagation on Three Phase Power Distribution Lines,” IEEE Tr. Power Delivery, 945-951, 1991.
S. Tachikawa and G. Marubayashi, “ DS/SS Communication Systems Sending with Reference PN Sequences for Power Line Data Transmission,” Electronics and Comms. in Japan, part I (Communications) pp. 68-79, 1992.
M. Tanaka, “High Frequency Noise Power Spectrum, Impedance and Transmission Loss of Power Line in Japan on Intrabuilding PLC,” IEEE Trans. on Consumer Electronics, pp. 321-326, May 1988.
M. Tanaka and R. Someya, “ The Noise Characteristics and Transmission Characteristics of Data Transmission using Power Line,” IEICE B, pp. 1147-1149, Oct. 1986.
J. Tengdin, “Distribution Line Carrier Communications- an Historical Perpective,” IEEE Tr. Power Delivery, 321-326, 1987.
S. Tsuzuki, T. Aibara, S. Tazaki, and Y. Yamada, “Error Rate Improvement of Powerline SS Communication Systems with FM-V5 Code and PRML Technique,” IEICE Fundamentals, pp. 1116-1123, Sept. 1992.
R. M. Vines, H. Trussell, Shuy and J. O’Neal. “ Impedance of the Residential Power Distribution Circuit,” IEEE Trans. on EMC, pp. 6-12, February 1985.
R. Vines, H.J. Trussell, L.J. Gale, and J.B. O’Neal Jr, “Noise on Residential Power Distribution Circuits,” IEEE Trans. on Electromagnetic Compatibility, vol. EMC-26, pp. 161-168, Nov. 1984.

Ph.D. Thesis

M. Beuttner, Synchronization Method for an OFDM Based Communication System in Powerline Applications, University of Karlsruhe, 1998.
P. Brown, Telecommunication Network for Remote Electricity Supply Metering and Load Control, Open University, England, May 1990.
J. Dickinson, High Frequency Modelling of Powerline Distribution Networks, Open University, 1996, England.
T. Esmailian, Frequency Response Measurement of Power Lines, Ph.D. Thesis, University of Totonto, Progress Report.
O. Hooijen, Aspects of Residential Power Line Communications, University of Essen, 1998.

In German:

Dipl.-Ing. M. Karl (1997), Möglichkeiten der Nachrichtenübertragung über elektrische Energieverteilnetze auf der Grundlage europäischer Normen, University of Karlsruhe.
Dipl.-Ing. M. Arzberger (1997), Datenkommunikation auf elektrischen Verteilnetzen für erweiterte Energiedienstleistungen, University of Karlsruhe.
Dipl.-Ing. T. Waldeck (1999), Einzel- und Mehrträgerverfahren für die störresistente Kommunikation auf Energieverteilnetzen, University of Karlsruhe.
Dipl.-Ing. M. Zimmermann (2000), Energieverteilnetze als Zugangsmedium für Telekommunikationsdienste, University of Karlsruhe.