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Introduction

The Editors

Power Line Communications (PLC) is currently an emerging technology, consequently it is attracting much attention. Research in PLC, which was formerly only low key, has intensified since the mid-1990s, attracting researchers and engineering practitioners from universities, industry and utility companies.

With this book we set out to create a wide-ranging introduction to PLC, ranging from channel characterization, communications on the physical layer and electromagnetic interference, through protocols, networks, standards and up to systems and implementations. We attempted to collate in one document information widely dispersed in the literature, often in hard-to-read research papers, and also in some cases obtainable only in standards which may still be in draft form. Selected topics from accepted practices and procedures, as well as from ongoing research, are covered. We sincerely hope that this book will also stimulate further research into the interesting but difficult topic of PLC.

Let us start by reviewing the historical development and some important issues concerning the general application of PLC, making ample use of the encyclopaedic overview article [1]. PLC has been studied for many years, although it has never been in the main stream of communications research activities. Early work in the twentieth century, with the goal of switching in substations, metering and basic load control can be attributed to Swiss engineers. During World War II, some radio amateurs experimented with PLC, when their activities on the Radio Frequency (RF) spectrum were restricted. As early as June 1954, the American Institute of Electrical Engineers (AIEE) published a report: ‘Guide to Application and Treatment of Channels for Power Line Carrier’. (For an updated version refer to reference [2].) Since then, much research has been done. Interest increased during the 1980s and intensified especially during the 1990s. A significant body of work has now been published in the research literature, as evidenced by the many references listed in this book. In fact, a number of subsystems and full systems have also been available from vendors for several years now.

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Electrical power lines are usually classified into the high (>100 kV), medium (1–100 kV) and low (<1 kV) voltage networks, with respectively increasing communications difficulties. (Note that the above voltages represent rather loose bounds on the effective values, measured between phases in a three-phase network.) The main thrust of the research into PLC has been focused on low voltage (LV) electrical power distribution networks, which have also geographically the widest spread, and which usually have the most convenient access within various buildings and structures. It should, however, be noted that these LV electrical networks turn out to be rather hostile and unusual channels, due to the fact that their design never involved communications aspects. Most of the material in this book is thus focused on developing communication systems for the LV network.

Historically, the utility organizations have been an important driving force behind the development of PLC. A primary motivation has been to do load management. This is usually achieved by selectively switching off, at time of peak demand, such devices as water heaters, which consume much energy on the demand side. Some countries have employed a ripple control system for this purpose. A ripple control system is a unidirectional system with low data rates that typically operates in the frequency band below 3 kHz, and has the disadvantage that it may require several megawatts for information transmission. PLC is a much more sophisticated method, requiring much less power to achieve load management as well as several other functions.

A second important motivation in the development of LV PLC systems has been to facilitate meter reading from a distance. Potentially this may include not only electricity meters, but also water, gas and temperature meters. Developments in this direction were started in the USA, where meter reader salaries were relatively high and electricity companies have not been allowed to charge their customers fixed monthly amounts, as was sometimes the case in Europe [3]. It is interesting to note that an English study [4] showed that a human meter reader achieves an average information rate of only about 1 bit/s! This is indeed very low compared to what is possible with modern PLC systems. The metering information, apart from automatic billing, may be used for additional customer functions, such as warnings when no pay has been received or even disconnecting nonpayers. In recent years some developing countries have installed prepaid electricity facilities, without which it would have been economically impossible to provide electricity to their many low-income users. Within prepaid electricity facilities, PLC plays an indispensable role.

Electrical utility companies may, furthermore, use PLC to shut off parts of the network in the event of danger, to gather user statistics, to transmit information to selected users, or to broadcast simultaneously to all users. Due to concerns about the worldwide energy crisis, rising fuel costs and global warming, electrical power utility companies are currently placing much emphasis on the concept of the ‘Smart Grid’. Here, digital communications will be the backbone. Many utilities prefer to have full control over their own communications infrastructure, for economic and strategic reasons. It will be cost effective to use PLC at least for some of the communications links in a smart grid.

Disaster recovery, whether from natural or manmade disasters, is also currently a serious consideration. In the event of longer term power cuts to cellular and wireless communications equipment, using PLC may become the only option over some critical links.

Home automation and intelligent buildings represent another growing application area. On the physical communications level, PLC provide a natural communications link for various devices, such as the sensors of an alarm system. On a higher systems level, several research investigations and product developments have focused on employing the LV network as a local area network for conveniently connecting many different computers or consumer electronic systems in the same building.

The feasibility of several simultaneous frequency multiplexed analog voice channels has early in the history of PLC been demonstrated on the High Voltage (HV) network. The earliest systems were fixed carrier, analogue systems. Carrier frequencies up to 500 kHz were sometimes used. With power levels up to 80 W, ranges of several hundred kilometers could be achieved without repeaters (see, e.g., references [5, 6]). Several systems providing voice communications over the HV network currently still work on these principles.

During the last decade, a number of pilot installations in different countries demonstrated the possibility of PLC to carry telephony (voice traffic), within a confined geographical area. In this way local access to the national telecommunications network may also become possible. This approach is especially attractive in developing countries. In these countries it is sometimes beneficial to employ the same costly cable infrastructure for dual purposes. Of special interest are the remote or geographically isolated villages where cellular telephony may not be economically feasible.

The scope for investigating future innovative applications is still wide open. For example, the transmission of slow scan television images over long distances can in many countries be used for security purposes and for the monitoring of distant installations. In developing countries, such a video communications facility may also be used, in conjunction with an audio channel, to realize broadcasts containing information or educational content to users, including remote and isolated communities.

PLC is usually considered as a retrofit facility, i.e. the electrical power reticulation network has already been installed and an advantage is thus that there are no additional costs pertaining to cables and related infrastructure. Also, the power network has the advantage of being an independent communications network. The HV and Medium Voltage (MV) networks cover long distances. During the last decades, many electricity companies have set up a fibre optic network in parallel to the HV network, mainly for signaling purposes. Only a fraction of the capacity of this fiber optic network is typically used, and it could therefore very well be used to form an extended telecommunications network, together with PLC systems operating on the MV and LV networks. The geographic coverage of the LV network is usually very wide where human habitation exists, and access to this network can be simple.

On the other hand, as stated before, power lines represent a particularly difficult communications environment. The noise on the PLC channel has very unusual characteristics and the noise levels may be excessive. The cable attenuation at frequencies of interest to communications is usually very large. Repeaters may thus be needed to compensate for cable losses, and to bridge over distribution transformers. Standing waves on long cables may lead to nulls in the frequency response. Care should be taken to circumvent the potential problem of large valued capacitors or inductors that may arise when designing for Low Frequency (LF) work. Furthermore, electromagnetic compatibility problems arise when interfacing electronic circuits with electrical power lines. To compound matters, important channel parameters such as impedance and attenuation, as well as the noise levels, fluctuate with time and load in a very unpredictable way.

Electromagnetic interference, possibly inflicted by PLC equipment to other users of the RF spectrum, is of much concern. Consequently, countering this interference is an important research area. An imperative focus of the standards for PLC developed during recent years has indeed been to minimize this interference. Note that we can distinguish between compliance standards and enforcement standards. The latter can be seen as mandatory regulations.

It has thus become practice to constrain the transmission parameters of the PLC channel by international or national enforcements standards. Perhaps the most important signaling parameters which are specified by regulations and standards, are the maximum transmitted power and the allowable frequency bands. These parameters are restricted in order to prohibit or limit the interference with other telecommunications services, and to prevent further pollution of the electromagnetic spectrum.

It is interesting to note that one of the first directives was published in 1974 by the Deutsche Bundespost: the 'Technische Richtlinie für TF-Funkanlagen für industrielle und gewerbliche Zwecke' [7]. Briefly, this early directive made provision for 5 mW of transmitted power within one channel covering 30–146 kHz. Later standards for narrowband PLC, such as the widely accepted CENELEC 50065-1 standard followed and extended this early standard. This was followed by standardization activities from industry, standards bodies and professional societies.

Usually, narrowband PLC refer to low rate digital communications utilizing the frequency band below 150 kHz in Europe (following the CENELEC standard: 3–148.5 kHz), and below 450 kHz in the USA and some far eastern countries. To achieve higher data rate communications, wider bandwidths and hence higher upper frequencies became necessary, as dictated by the fundamental theorems from information theory and communications. Wideband PLC thus utilizes a much wider frequency band, with lowest frequency being typically 1 MHz, and with highest frequency typically up to 30 or 60 MHz. The use of higher upper frequencies, even extending into hundreds of MHz, has also been investigated and implemented – regulations vary between countries.

The most important factor delaying wider installation and use of PLC, especially wideband communications, has been the rather slow development of standards acceptable to all participants. Agreement on emission limits has been a key obstacle. The progress made in recent years on standards is also reported in this book. It should be noted that in general the category of 'wire-line systems' includes not only PLC systems, but also asynchronous digital subscriber loops and cable modem systems. Some standardization and regulation activities address this broader context of systems.

Through the years, different names and acronyms have been used for this interesting research and application area in communications. These terms have sometimes been confusing and even nebulous. Some alternative terms used through the years seem to have been PLT to denote Power Line Telecommunications or Power Line Transmission and DLC to denote Distribution Line Communications (i.e. communications for the LV network). PLC has once been used to denote Power Line Carrier (i.e. communications for the HV network). On the other hand, there seems to be wider agreement on using the acronym BPL to denote Broadband PLC, i.e. high data rate PLC requiring a wideband channel.

In this book we prefer the term 'Power Line Communications' and acronym PLC to encompass the whole field of communications over LV, MV and HV lines, whether narrowband or wideband. Here, we follow the trend set by the most influential conference in this field, namely the annual International Symposium on Power Line Communications or ISPLC, which was initiated at the University of Essen in 1997, and which became an official conference of the IEEE Communications Society in 2006. ISPLC has served as a very important forum for, and catalyst of research into PLC. A data base containing the full papers of the earlier ISPLC conference proceedings was initially established at the University of British Columbia, and is currently available under the auspices of the IEEE Communications Society at reference [8]. It now also provides links to other papers published in IEEE journals and conferences since 1986, and also to papers published in journals by Wiley, Elsevier and Hindawi, etc. The large body of ISPLC papers published up to now provided an important foundation of necessary material and also an inspiration for this book.

The rest of this book is constituted as follows.

The characterization of power lines and power distribution networks as a transmission medium for digital communications is one of the very first and fundamental steps towards successful design and implementation of PLC systems. Chapter 2 thus provides an overview of the state of the art in channel characterization for PLC.

The electromagnetic compatibility environment associated with any wire-line service is a cardinal factor when deploying it. Chapter 3 introduces the electromagnetic effects associated with wire-line systems, especially the specific issues of PLC and the potential to cause interference to established communication services.

Chapter 4 considers the coupling of the communications signal to the power line network. This is an underinvestigated topic with very scarce coverage in the literature, yet it can potentially yield a large gain in signal-to-noise ratios.

Digital transmission, the core of any communications system, is investigated for PLC systems in Chapter 5. We describe several contenders for modulation and coding, for both narrowband and wideband PLC systems. Widely accepted signaling techniques, as well as recent research results on promising new signaling techniques, are reported.

Networks and protocols reside on the top layer of PLC systems and may interface between the PLC system and an unusual mix of users. New protocols need to be developed because of the unusual interference on the physical channel, and the topology of LV distribution networks, which is different from other telecommunications networks. In Chapter 6 we consider a few different scenarios, representative of some practical or potential applications.

All wire-line and telecommunication services are expected to coexist with all other services. While communication standards are developed throughout the world, some standards are best established for local conditions in a particular country or continent. Chapter 7 provides an overview of standards and standardization activities, some of which may still be evolving.

In Chapter 8, a number of PLC systems and implementation scenarios are discussed to illustrate the potential and the ability of PLC technology for commercially viable communication solutions.

Finally, in the conclusions in Chapter 9 we consider some issues related to the future development and deployment of PLC.

References

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