BROADBAND POWERLINE COMMUNICATIONS

NETWORK DESIGN

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Broadband Powerline Communications Networks

To my parents, with love and respect

H. Hrasnica

Preface

Access networks implement the inter-connection of the customers/subscribers to wide-area communication networks. They allow a large number of subscribers to use various telecommunications services. However, the costs of realization, installation, and maintenance of access networks are very high, very often representing more than 50% of the investment in the network. Therefore, network providers try to realize the access network at as low a cost as possible to increase their competitiveness in the deregulated telecommunications market. In most cases, access networks are still the property of incumbent network providers (e.g., the former monopolistic telephone companies). Because of that, new network providers try to find solutions to realize their own access networks. A promising possibility for the realization of access networks is offered by the PowerLine Communications (PLC) technology.

PowerLine Communications technology allows the usage of electrical power supply networks for communications purposes and, today, also broadband communication services. The main idea behind PLC is the reduction in operational costs and expenditure for realization of new telecommunications networks. Using electrical supply networks for telecommunications has also been known since the beginning of the twentieth century. Thus high-, medium- and low-voltage supply networks have been used for internal communications of electrical utilities and for the realization of remote measuring and control tasks. PLC is also used in internal electrical installations within buildings and homes (the so-called in-home PLC) for various communications applications. Generally, we can divide PLC systems into two groups: narrowband PLC allowing communications services with relatively low data rates (up to 100 kbps) and ensuring realization of various automation and control applications as well as a few voice channels, and broadband PLC systems allowing data rates beyond 2 Mbps and, accordingly, realization of a number of typical telecommunications services in parallel, such as telephony and internet access.

Broadband PLC in low-voltage supply networks seems to be a cost-effective solution for "last mile" communications networks, the so-called PLC access networks. Nowadays, there are many activities concerned with the development and application of PLC technology in the access area. Thus, we find a number of manufacturers offering PLC products that ensure data rates between 2 and 4 Mbps and announcing new PLC systems with data rates up to 45 Mbps or more. There are also numerous PLC field trials worldwide, as well as several PLC access networks in commercial use. The number of PLC subscribers is still growing. A similar development in medium-voltage and in-home PLC networks is in progress as well. On the other hand, there are no existing standards for broadband PLC networks, which are supposed to use a frequency range up to 30 MHz. In particular, the problem of electromagnetic compatibility of PLC systems with reference to their coexistence with other telecommunications systems, such as various radio services, has not yet been completely solved. Therefore, PLC technology is now in a very important development phase that will determine its future, its application areas, and its penetration into telecommunications world in competition with other broadband technologies.

Because of the absence of standards and, understandable, detailed publication of sensitive research material by PLC manufacturers, there is very little information on broadband PLC systems and networks in the literature. We find a number of papers, several dissertations, and a few books covering different, mainly very specific, research areas, which are not suitable for the wider community of readers. On the other hand, there are many publications describing general PLC-related topics but without, or with very little, technical content. Therefore, it is necessary to provide complete information on broadband PLC networks that includes both general information on PLC technology and also offers technical details that are important for the realization of PLC systems. The book "Powerline Communications" by Klaus Dostert covers mainly narrowband PLC technology, and it focuses more on the transmission aspects of PLC.

This book contributes to the design aspects of broadband PLC access systems and their network components. The intention of this book is to explain how broadband PLC networks are realized; what the important characteristics, as well as environment, for the transmission through electrical power grids are; and what implementation solutions have been considered recently for the realization of broadband PLC systems.

The authors of this book, all of them from the Chair for Telecommunications at Dresden University of Technology – Germany, have been involved in the research and development of PLC networks and systems for several years. Our department has participated in several international industry and EU supported research projects on PLC and cooperated with a number of partners also involved in the actual development of this technology. The chair is a member of the PLC Forum. The authors have published more than 20 research publications on broadband PLC access networks, performance evaluation of PLC systems, modeling PLC networks, and development of PLC MAC layer and its protocols. In our department, we have developed a simulation tool called PAN-SIM (PLC Access Network Simulator), used for performance analysis of PLC networks, which has also been presented in several trade fairs and specialized conferences.

This book has been written for the following groups of readers:

- Lecturers (professors, PhD researchers), for research and educational purposes at universities
- Developers of PLC equipment, systems, interfaces, and so on.
- Network engineers at potential PLC network operators
- Business people, managers, or policy makers who need an overview of PLC technology and its possibilities, and of course
- Students with an interest in PLC and other telecommunications technologies.

During our work on this book, many people have supported us in different ways. Therefore, we would like to thank them. First, we would like to thank all our colleagues at the Chair for Telecommunications, Dresden University of Technology – Germany, for their valuable professional help and for creating the friendly atmosphere in our department that really helped us complete this project. We also have drawn considerably from our involvement in several research projects. Therefore, we would like to thank all our partners in the PALAS project in the 5th framework programme of the European Community and our colleagues from Regiocom (Magdeburg) and Drewag (Dresden). Our sincere thanks go to all the students who helped us during the work on PLC and to numerous colleagues worldwide with whom we had very useful discussions on various occasions.

Dresden, January 2004

Halid Hrasnica, Abdelfatteh Haidine, Ralf Lehnert

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Introduction

During the last decades, the usage of telecommunications systems has increased rapidly. Because of a permanent necessity for new telecommunications services and additional transmission capacities, there is also a need for the development of new telecommunications networks and transmission technologies. From the economic point of view, telecommunications promise big revenues, motivating large investments in this area. Therefore, there are a large number of communications enterprises that are building up high-speed networks, ensuring the realization of various telecommunications services that can be used worldwide. However, the investments are mainly provided for transport networks that connect various communications nodes of different network providers, but do not reach the end customers. The connection of the end customers to a transport network, as part of a global communications system, is realized over distribution and access networks (Fig. 1.1). The distribution networks cover larger geographical areas and realize connection between access and transport networks, whereas the access networks cover relatively smaller areas.

The direct connection of the customers/subscribers is realized over the access networks, realizing access of a number of subscribers situated within a radius of several hundreds of meters. However, the costs for realization, installation and maintenance of the access networks are very high. It is usually calculated that about 50% of all network investments belongs to the access area. On the other hand, a longer time is needed for paying back the invested capital because of the relatively high costs of the access networks, calculated per connected subscriber. Therefore, the network providers try to realize the access network with possibly low costs.

After the deregulation of the telecommunications market in a large number of countries, the access networks are still the property of incumbent network providers (former monopolistic telephone companies). Because of this, the new network providers try to find a solution to offer their own access network. An alternative solution for the realization of the access networks is offered by the PLC (PowerLine Communications) technology using the power supply grids for communications. Thus, for the realization of the PLC networks, there is no need for the laying of new communications cables. Therefore, application of PLC in low-voltage supply networks seems to be a cost-effective solution for so-called "last mile" communications networks, belonging to the access area. Nowadays, network subscribers use various telecommunications services with higher data rates and

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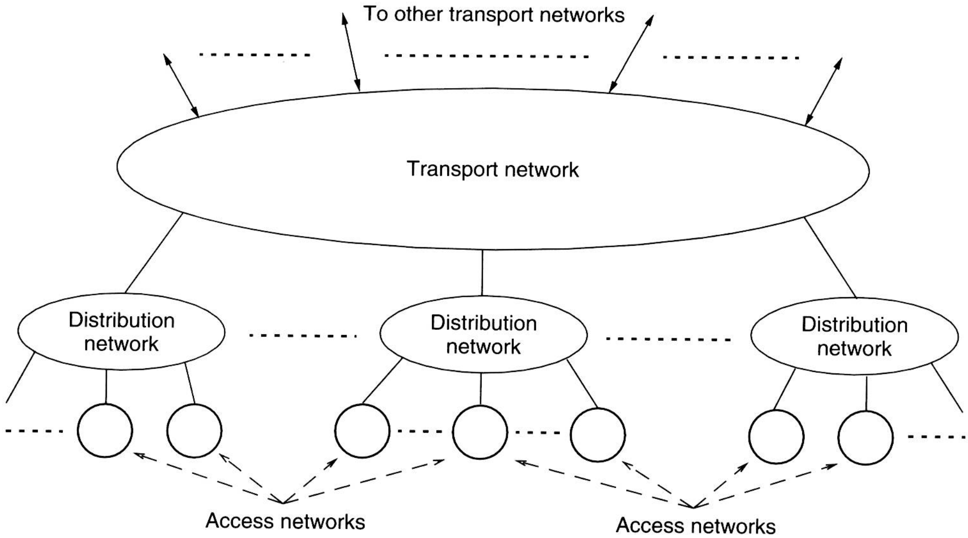

Figure 1.1 Telecommunications network hierarchy

QoS (Quality of Service) requirements. PLC systems applied in the access area that ensure realization of telecommunications services with the higher QoS requirements are called “broadband PLC access networks”. The contribution of this book is directed to give a set of information that is necessary to be considered for the design of the broadband PLC access systems and their network components.

To make communications in a power supply network possible, it is necessary to install so-called *PLC modems*, which ensure transmission of data signals over the power grids (Fig. 1.2). A PLC modem converts a data signal received from conventional communications devices, such as computers, telephones, and so on, in a form that is suitable for transmission over powerlines. In the other transmission direction, the modem receives a

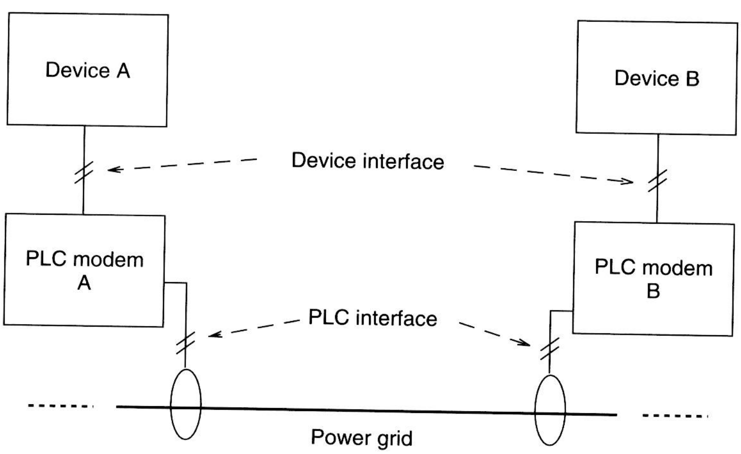

Figure 1.2 Communications over power grids

data signal from the power grids and after conversion delivers it to the communications devices. Thus, the PLC modems, representing PLC-specific communications equipment, provide a necessary interface for interconnection of various communications devices over power supply networks. The PLC-specific communications devices, such as PLC modems, have to be designed to ensure an efficient network operation under transmission conditions, typical for power supply networks and their environment.

However, power supply networks are not designed for communications and they do not present a favorable transmission medium. Thus, the PLC transmission channel is characterized by a large, and frequency-dependent attenuation, changing impedance and fading as well as unfavorable noise conditions. Various noise sources, acting from the supply network, due to different electric devices connected to the network, and from the network environment, can negatively influence a PLC system, causing disturbances in an error-free data transmission. On the other hand, to provide higher data rates, PLC networks have to operate in a frequency spectrum of up to 30 MHz, which is also used by various radio services. Unfortunately, a PLC network acts as an antenna producing electromagnetic radiation in its environment and disturbs other services operating in the same frequency range. Therefore, the regulatory bodies specify very strong limits regarding the electromagnetic emission from the PLC networks, with a consequence that PLC networks have to operate with a limited signal power. This causes a reduction of network distances and data rates and increases sensitivity to disturbances.

The reduction of the data rates is particularly disadvantageous because of the fact that PLC access networks operate in a shared transmission medium, in which a number of subscribers compete to use the same transmission resources (Fig. 1.3). In the case of PLC

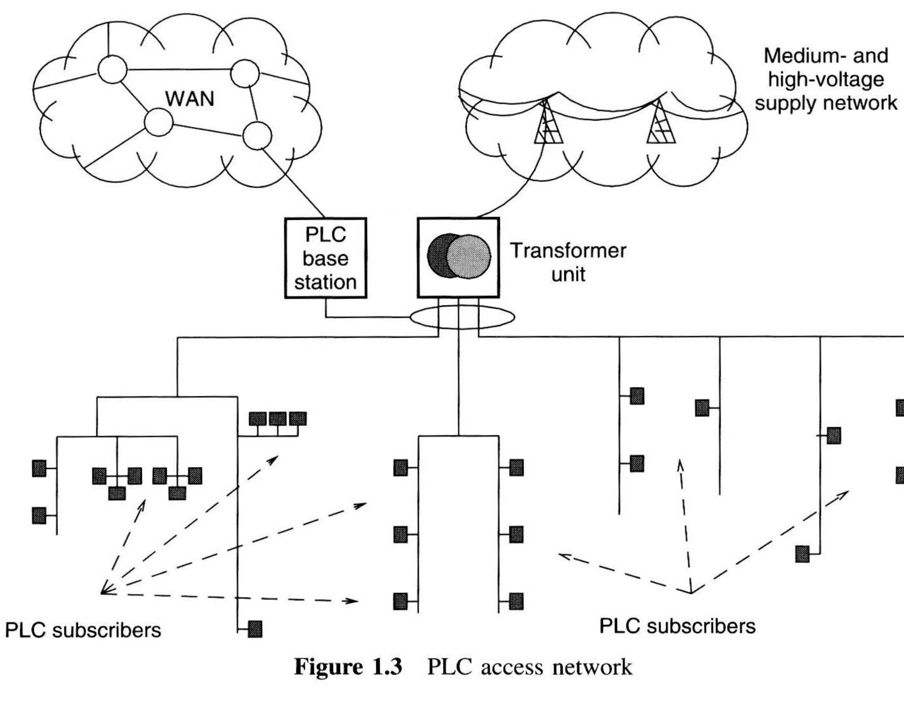

Figure 1.3 PLC access network

access networks, the transmission medium provided by a low-voltage supply network is used for communication between the subscribers and a so-called *PLC base station*, which connects the access network to a wide area network (WAN) realized by conventional communications technology.

To reduce the negative impact of powerline transmission medium, PLC systems have to apply efficient modulation, such as spread spectrum and Orthogonal Frequency Division Multiplexing (OFDM). The problem of disturbances can also be solved by well-known error-handling mechanisms (e.g. forward error correction (FEC), Automatic Repeat reQuest (ARQ)). However, their application consumes a certain portion of the PLC network capacity because of overhead and retransmission. On the other hand, a PLC access network has to be economically efficient, serving possibly a large number of subscribers. This can be ensured only by a good utilization of the limited network capacity. Simultaneously, PLC systems have to compete with other access technologies (e.g. digital subscriber line (DSL), cable television (CATV)) and to offer different telecommunications services with a satisfactory QoS. Both good network utilization and provision of QoS guarantees can be achieved by an efficient Medium Access Control (MAC) layer.

Nowadays, there are no existing standards or specifications considering physical and MAC layers for PLC access networks. The manufacturers of the PLC equipment developed proprietary solutions for the MAC layer that are incompatible with each other. Therefore, we consider various solutions for realization of both physical and MAC layers in broadband PLC access networks to be implemented in PLC-specific communications equipment, such as PLC modems (Fig. 1.3). Detailed description of the PLC physical layer, including consideration of the PLC network characteristics, such as transmission features and noise behavior, and consideration of modulation schemes for PLC, can also be found in another available book on this topic, "Powerline Communications", written by Prof. Dostert [Dost01], in which both the narrowband and broadband PLC systems are considered. In this book, we focus on the broadband access networks and describe characteristics of the physical layer and applied modulation schemes for the broadband PLC systems, and introduce an investigation of PLC MAC layer. Nowadays, the issue of the PLC MAC layer is only considered in a few scientific publications (e.g. [Hras03]). Therefore, in this book we emphasize a consideration of the MAC layer and its protocols to be applied in the broadband PLC access networks.

The book is organized as follows: in Chapter 2, we discuss the role of PLC in telecommunications access area and present basics about narrowband and broadband PLC systems, network structure with its elements and PLC-specific performance problems that have to be overcome for realization of broadband access networks. The characteristics of the PLC transmission medium are presented in Chapter 3, which includes a topology analysis of the low-voltage supply networks, description of the electromagnetic compatibility issue (EMC) in broadband PLC, noise characterization and disturbance modeling, as well as a description of the PLC transmission channel and its features. In Chapter 4, we present a protocol architecture for PLC networks and define PLC-specific network layers. Later, we describe spread spectrum and OFDM modulation schemes, which are outlined as favorable solutions for PLC. Furthermore, various possibilities for realization of error handling in PLC systems are considered. Finally, in Chapter 4, we analyze telecommunications services to be used in PLC networks and specify traffic models for their representation in investigations of the PLC networks. The MAC layer, as a part of the common PLC protocol architecture, is separately analyzed in Chapter 5. We introduce different solutions of multiple-access schemes and consider various MAC protocols for their application in PLC. Furthermore, several solutions for traffic control in PLC networks are discussed. Finally, in Chapter 6, we present a comprehensive performance evaluation of reservation MAC protocols, which are outlined as a suitable solution for application in broadband PLC access networks. In this investigation, we compare various signaling MAC protocols under different traffic and disturbance conditions, representing a typical user and noise behavior expected in broadband PLC access networks.