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## INTRODUCTION

The explosive growth of the Internet has led to the need for ubiquitous data and multimedia communications in the twenty-first century. In-home distribution of multimedia content is still a challenge, particularly for homes not equipped with specialized wiring to support high-speed data and multimedia communications. Retrofitting buildings with new wiring is prohibitively expensive and wireless solutions do not reliably provide “whole house” coverage for multimedia applications. Hence, the need arises for a new LAN technology that enables affordable and ubiquitous connectivity within the home. The existing electrical wiring is unique in that it provides a large number of connection points throughout the home, eliminating a significant limitation of other existing wires, specifically coax cables or traditional telephone lines. However, unlike the relatively clean communication coax and phone line channel, there are many challenges in communication over the harsh powerline channel that must be overcome to make powerline communication (PLC) a viable “no new wires” home networking solution for high speed multimedia applications.

This book provides a clear and simple overview of key features of the HomePlug AV specification and the associated IEEE 1901 standard. It provides details on how the challenges associated with communicating over the electrical wiring were overcome and also the justifications and explanations of the reasoning behind the technical decisions that were made in the specification. The reader is referred to the HomePlug AV specification and the IEEE 1901 standard for the technical details needed for implementation. The book primarily focuses on HomePlug AV and discusses the IEEE 1901 standard, highlighting the features of HomePlug AV that

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*HomePlug AV and IEEE 1901: A Handbook for PLC Designers and Users*, First Edition.

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have been incorporated into the standard, as well as providing a description of key provisions of IEEE 1901 standard. The book also gives an overview of the HomePlug Green PHY specification that targets Smart Energy applications (10 Mbps) and the HomePlug AV 2.0 specification that adds MIMO, repeating, and other enhancements to HomePlug AV, thus providing operation up to 1.5 Gbps.

## 1.1 HomePlug AV AND ITS RELATIONSHIP TO IEEE 1901

The HomePlug AV 1.1 specification [1] (referred to throughout this book as HomePlug AV) was released in May 2007 by the HomePlug Powerline Alliance. At that time HomePlug AV was the flagship specification in an emerging PLC suite by the HomePlug Powerline Alliance, including the HomePlug 1.0.1 specification (2001). The HomePlug AV specification describes a PLC system operating at 200 Mbps and built upon an Orthogonal Frequency-Division Multiplexing (OFDM) FFT-based physical layer (PHY) protocol and a hybrid TDMA/CSMA Medium Access Control (MAC) protocol. The CSMA component is identical to that used in the HomePlug 1.0.1 CSMA technology. The OFDM FFT PHY uses the frequency band of 1.8–30 MHz with modulation up to 1024 QAM and a turbo convolutional code FEC.

The emergence of the HomePlug Powerline Alliance specifications together with a number of other incompatible industry-driven PLC specifications led to the need for a globally coordinated PLC standard. Industry organizations such as the HomePlug Powerline Alliance with membership open to competing PLC companies made some attempts at generating consensus on design choices in specification development. However, competing corporate interests often made this a very difficult and often impossible process.

In 2005, the IEEE Communications Society (COMSOC) sponsored the IEEE P1901 project to define a global IEEE standard for high-speed PLC systems. Several competing proposals were considered from research and development groups and manufacturers of PLC equipment in Europe, Asia, and the Americas. In 2007, about the same time as the release of the HomePlug AV 1.1 specification, the IEEE 1901 working group selected a consolidated proposal by the HomePlug Powerline Alliance and the HD-PLC Alliance. The final proposal featured three technology areas or “clusters,” namely, the In-home cluster, the Access cluster, and the Coexistence cluster, and the approved IEEE 1901 standard [2] was published in December 2010. IEEE 1901 represented a standard of compromise between the FFT-based OFDM PHY in HomePlug AV and the Wavelet-based OFDM PHY used in Panasonic’s HD-PLC devices. The standard specifies both PHYs as optional, with an Intersystem protocol (ISP) providing coexistence but not interoperability between the in-home FFT and Wavelet PHY realizations of IEEE 1901. This compromise with two noninteroperable PHY specifications is, in reflection, analogous to the case of the original IEEE 802.11 standard that was released with two noninteroperable PHY specifications, namely, the direct-sequence and frequency-hopping spread spectrum. In addition to enabling coexistence between these noninteroperable PHYs, the ISP is

also designed to ensure coexistence between in-home IEEE 1901 system and IEEE 1901 Access or G.hn systems.

While both the HomePlug AV and the newer IEEE 1901 specifications contemplated and provided for coexistence with PLC Access systems, at present efforts to build or deploy HomePlug AV- or IEEE 1901-based PLC Access systems are at best in the very early stages. Though the technology for Access systems is available and technically viable, past experience with PLC-based systems for Internet access has been commercially unsuccessful in the United States and Europe. However, the emergence of Smart Grid and Smart Energy market drivers may portend new developments in this area in the near future.

In the present-day in-home PLC market, in the absence of interoperability, the major emphasis is on manufacturing HomePlug AV devices with IEEE 1901 certification to ensure coexistence guarantees as outlined above. At the same time, IEEE 1901 PLC devices with non-HomePlug options may still be deployed with guaranteed coexistence. The legacy HomePlug AV devices and newer IEEE 1901-certified devices with the HomePlug FFT currently have the largest market penetration and momentum globally.

## 1.2 FOCUS OF THE BOOK

Numerous scholarly papers, white papers, and reports have been published that present individual aspects of the HomePlug AV specification and the IEEE 1901 standard, and of course there is full technical specification of each. The IEEE 1901 standard can be purchased from the IEEE and the full HomePlug AV specification is available to members of the HomePlug Powerline Alliance. In contrast, the goal of this handbook is to provide a comprehensive yet clear and simple description of HomePlug AV and the IEEE 1901 standard that will be useful to designers of HomePlug compliant devices and also accessible and beneficial to network administrators and individual users of compliant PLC networks. From this perspective, the main focus of the book will be on HomePlug AV with relevant details from IEEE 1901 presented to clarify how IEEE 1901 is built upon and expands on HomePlug AV technologies.

In the fact, if we consider an IEEE 1901 compliant device with the FFT HomePlug AV-based FFT option for the PHY, what we have is essentially an augmented HomePlug AV system with certain extensions to the HomePlug AV 1.1 PHY and MAC, as well as the mechanisms to enable coexistence with IEEE 1901 devices with the Wavelet PHY option and with G.hn and IEEE 1901 Access systems. In summary, the extensions of the of the HomePlug AV PHY include (i) the extension of the frequency band from 1.8–30 to 1.8–50 MHz, (ii) a larger set of guard intervals—some shorter and some larger than that in HomePlug AV, (iii) a higher code rate—8/9 to complement the 1/2 and 16/21 code rates, and (iv) a higher order modulation—4096 QAM (the HomePlug AV maximum was 1024 QAM). MAC augmentations include (i) the addition of repeating, which was not present in HomePlug AV 1.1, (ii) adjustments to the Short Network IDentifiers (SNID), and (iii) the addition of the ISP for coexistence [2].

The book will not only provide a general understanding of the features and capabilities of HomePlug AV but will also give sufficient details of the PHY and MAC and other features to be helpful to PLC product designers. The book will be a supplement and guide to the HomePlug AV specification and the IEEE 1901 standard and will provide background on the evolution and development of the related specifications and standards.

### 1.3 THE HomePlug POWERLINE ALLIANCE

The HomePlug Powerline Alliance is a powerline networking industrial association that was formed in 2000 to promote the rapid development and adoption of powerline communications solutions. The charter of the alliance is to develop specifications and certification programs for using the powerlines for reliable home networking and Smart Grid applications. HomePlug is the largest and most established industry group for PLC, with about 65 member companies. The HomePlug specifications were designed specifically to serve a number of in-home digital entertainment and networking applications. These include easy access to services such as online video and music programming from anywhere with a power outlet, high-speed PLC broadband connections to HDTV's, Blu-ray players, DVRs, PCs, and game consoles, as well as general purpose in home computing. As of early 2012, there are a number of different HomePlug chipsets available from at least 6 vendors and close to 280 different HomePlug PLC products, with HomePlug products controlling over 90% of the broadband PLC market and over 100 million HomePlug products shipped worldwide.

#### 1.3.1 HomePlug Specifications

Toward achieving the goals of its charter, in the last decade the HomePlug Powerline Alliance has released or has been a major contributor to a range of PLC specifications and standards operating between 14 Mbps and 1.5 Gbps. Table 1.1 shows the timeline and data rate supported by six such specifications and standards.

With this suite of specifications and associated products, the HomePlug Powerline Alliance is well poised to make a significant contribution to the converged digital and

**TABLE 1.1 HomePlug Specifications Timeline**

Specification/Standard	Ratification/Publication Date	Data Rate Supported
HomePlug 1.0.1	December 2001	14 Mbps
TIA-1113 (HomePlug 1.0.1)	May 2008	14 Mbps
HomePlug AV v1.1	May 2007	200 Mbps
IEEE 1901	December 2010	400 Mbps
HomePlug Green PHY v1.0	August 2010	10 Mbps
HomePlug AV v2.0	March 2012	1.5 Gbps

Smart Grid networking requirements, with products that are both compatible and interoperable. In fact, HomePlug AV is one of the four technologies (the others being Wi-Fi [3] (IEEE 802.11x [4]), Ethernet (IEEE 802.3 [5]), and MoCA [6]) that will form the new IEEE 1905.1 standard that provides a common interface for the most compelling converged home networking technologies, in support of interoperable voice, video, and data services inside the smart home.

### 1.3.2 How the HomePlug AV Specification Was Developed

The HomePlug Industrial Alliance uses a well-streamlined process in the development of all its specifications, somewhat paralleling the operation of other standards organizations such as the IEEE.

For the HomePlug AV specification, the process started with the HomePlug Board of Directors (BoD) appointing a committee to develop a Marketing Requirements Document (MRD) that specifies what features and characteristics HomePlug AV should have in order to address the perceived needs.

The MRD included several typical cases of multiple multimedia video sessions, IP telephony sessions, gaming sessions, and data networking applications occurring simultaneously and specified the target range of aggregate data rate that HomePlug AV should support. A Technology Evaluation Group (TEG) was also appointed by the BoD and the TEG issued a request for proposals for technologies that could meet the MRD. The TEG reviewed submissions and made the baseline selection of core technologies from multiple submissions that would form the basis of the HomePlug AV specification. Since no member company had all the requisite technologies in their portfolio, HomePlug AV was developed from a merger of ideas from several HomePlug member companies.

Finally, the HomePlug AV specification was developed through much laborious and intensive work by the HomePlug AV Technical Working Group (TWG), which produced the HomePlug AV 1.1 specification published in May 2007. Note that although HomePlug AV version 1.0 specification was published in December 2005, version 1.1 became the definitive HomePlug AV base specification since it was published about the time the first AV products were introduced to the market.

Various members of the HomePlug Powerline Alliance participated in the IEEE 1901 standardization efforts, contributing technologies and solutions to the various challenges faced in the development of this important global PLC standard.

One may now regard the present relationship between IEEE 1901 and HomePlug as being similar to the relationship between IEEE 802.11 and Wi-Fi (the Wi-Fi Alliance). Today the Wi-Fi Alliance certifies that wireless networking products conform to the 802.11x standard in much the same way as the HomePlug provides certification to PLC products as IEEE 1901 compliant. HomePlug will also provide certification for IEEE 1905.1 products that will feature HomePlug AV technology.

The *Compliance and Interoperability Working Group* (C&IWG) of the HomePlug Powerline Alliance is responsible for the processes and protocols for testing and certifying chips, devices, and products to be compliant with HomePlug specifications or IEEE standards. The C&IWG coordinates HomePlug Plugfests for multivendor

interoperability and compliance testing for the HomePlug AV specification and the IEEE 1901 powerline networking standard.

### 1.3.3 The Regulatory Working Group

The Regulatory Working Group (RWG) of the HomePlug Powerline Alliance is responsible for the development of strategy and processes to ensure that HomePlug products conform to global regulatory requirements. The design of PLC systems such as HomePlug AV and IEEE 1901 must also deal with these regulatory constraints. For example, in the United States, PLC systems operate under FCC Part 15 [7] rules in the frequency band between 1.8 and 30 MHz. Several subbands within this range are notched out in HomePlug products to prevent interference in licensed services. Moreover, the regulatory environment in Europe is in flux: aeronautical bands may be added and power levels are under debate. Japan made amendments to their regulations in 2006 that enabled in-building PLC and is currently considering further amendments that would allow outdoor PLC. This relatively unstable international regulatory environment requires that PLC systems be flexible to adapt to changing regulations.

In sections 1.3.3.1–1.3.3.3, we consider the present PLC regulatory domains in the United States, Europe, and the rest of the world.

**1.3.3.1 The United States and the FCC** Regulations for powerline communications in the United States are established by the Federal Communications Commission (FCC) and are specified in Title 47 of the Code of Federal Regulations, Part 15 [7]. The FCC rules define “Access Broadband over Power Line” (Access BPL) and “In-House Broadband over Power Line” (In-House BPL).

In-House BPL is defined as “A carrier current system, operating as an unintentional radiator, that sends radio frequency energy by conduction over electric powerlines that are not owned, operated or controlled by an electric service provider. The electric powerlines may be aerial (overhead), underground, or inside the walls, floors or ceilings of user premises. In-House BPL devices may establish closed networks within a user’s premises or provide connections to Access BPL networks, or both.”—47 CFR Ch. I (10–1–10 Edition), § 15.3 [7].

**1.3.3.1.1 FCC Compliance Testing** Part 15.31 (d) [7] specifies that carrier current devices be tested for compliance with the FCC regulations in three typical installations. The ANSI C63.4-1992 [8] document gives details concerning how to install the test equipment and how to make the measurements. The equipment is installed in a typical operating scenario, usually with a transmit duty factor very close to 100%. Measurements are then made at 16 equally spaced radials around the periphery of the house in which the equipment is operating. Measurements are made with a loop antenna in the H-field, with the antenna centered 1 m above the ground and oriented to maximize the readings.

The equipment built to the HomePlug specification and providing nominally the highest signal level permitted by the HomePlug specification is tested for compliance

with Part 15 requirements in three typical home installations. The powerline modem under test is plugged into an electrical outlet that is on an exterior wall. Tests are usually conducted by independent FCC-certified test labs such as Compatible Electronics of Brea, CA, for west coast locations and Product Safety Engineering of Dade City, FL, for the east coast.

The FCC Part 15 requirement for unlicensed devices, including PLC, is that the device may not cause “harmful interference.” Regulatory compliance testing ensures that products bearing the HomePlug or IEEE 1901 stamp do not cause such harmful interference. If the FCC receives a report of harmful interference from a HomePlug or IEEE 1901 PLC device, the manufacturers may refer to the testing protocol and results, but will be also be required to respond to the complaint to remove the harmful interference.

Notching amateur band is not required by FCC Part 15. However, HomePlug PLC devices notch the amateur frequency bands to avoid interference in these bands. HomePlug Compliance testing evaluates both the quality and effectiveness of the notching implemented in the target devices to ensure compliance with the HomePlug specification and the adherence to FCC rules across the spectrum.

**1.3.3.2 Europe, CISPR, and CENELEC** Although the European Union does not have an equivalent body as the U.S. FCC, PLC products sold in Europe are required to comply with the essential requirements of “Directive 2004/108/EC of the European Parliament and of the Council” [9].

This Directive regulates the electromagnetic compatibility of equipment. The following is the essential requirement:

*“Equipment shall be so designed and manufactured, having regard to the state of the art, as to ensure that:*

- (a) the electromagnetic disturbance generated does not exceed the level above which radio and telecommunications equipment or other equipment cannot operate as intended;*
- (b) it has a level of immunity to the electromagnetic disturbance to be expected in its intended use which allows it to operate without unacceptable degradation of its intended use.”*

The broad principles set forth in the Directive are given more explicit technical expression by harmonized European standards, yet to be adopted by the various European standardization bodies such as the European Committee for Standardization (CEN), the European Committee for Electrotechnical Standardization (CENELEC), and the European Telecommunications Standards Institute (ETSI).

Thus, the standards set by these organizations become, in essence, the PLC regulations for Europe and PLC devices can be put on the market or into service in the European Union only if the manufacturers concerned have established that such devices have been designed and manufactured in conformity with the requirements of this EU Directive. Approved devices should bear the “CE” marking attesting

their compliance (Conformité Européene) with the EU Electromagnetic Compatibility Directive.

To date, no formal harmonized standards for PLC have been adopted in Europe. Previous efforts in the Comité International Spécial des Perturbations Radioélectriques (CISPR) to amend CISPR-22 [10] specifying compliance testing procedures for powerline communications generated various draft standards, but these were never approved by CISPR member states. More recently, a draft standard has been created in CENELEC prEN50561-1 [11], which is largely based on the most recent draft from CISPR, and it is hoped that this draft will be ratified and approved.

CE mark certification can be obtained by having the devices tested by a “Notified Body” that is recognized and registered by the European Union. The testing organization will then apply state-of-the-art assessment, which in practice is based on the existing CISPR and CENELEC draft documents or related standards from other international organization such as the International Telecommunication Union—Radiocommunication (ITU-R). The “no harmful interference” approach allows static notching in spectral mask or even dynamic notching based on sensing the presence of interfering signals. The essential expectation is that there should be again “no harmful interference” and the manufacturers are held liable to respond to and rectify any legitimate complaints.

It should also be noted that in the European Union, individual countries are not bound by the above formative PLC regulations and can set their own independent standards for PLC.

**1.3.3.3 Rest of the World** Other countries apart from the European Union and the United States have a variety of stances on PLC regulations. Each country usually has the equivalent of a Public Utility Regulator that manages access to and use of radio frequency spectrum. Some countries are very open to the use of PLC technology, often adopting or adapting to the EU or U.S. standards, while others generate local standards. Each manufacturer of HomePlug or IEEE 1901 devices destined for such countries needs to ensure compliance with relevant regulations and the HomePlug Regulations Working Group ensures this for the HomePlug Powerline Alliance.

## **1.4 THE ROLE OF PLC IN MULTIMEDIA HOME NETWORKING AND SMART ENERGY APPLICATIONS**

Powerline communication has a unique role to play in the broad areas of in-home networking and Smart Energy applications.

HomePlug AV and IEEE 1901 have as a main target multimedia high speed in home networking in support of video, voice, gaming, and data services. PLC has the advantage of near whole house coverage with a large number of convenient outlets at data rates that are usable for high-speed applications. PLC products based on IEEE 1901 and HomePlug AV offer application data rates to support one or more HDTV channels. Most of the PLC products are individual adapters that include an Ethernet interface. Several manufacturers are now embedding HomePlug AV and IEEE 1901



devices directly into multimedia set-top boxes to allow media delivery over the PLC network. Some network routers are also now being made with both wireless and PLC interfaces.

Many competing technologies have also targeted the multimedia in-home market, the most well known being the wireless networking technologies based on the IEEE 802.11 (Wi-Fi) suite of protocols. Although Wi-Fi does provide a convenient mobile solution, it faces the challenge of whole house coverage with sustained and reliable throughput when subject to typical interferences. This situation is especially challenging when Wi-Fi is used in large residences and those made of solid concrete walls through which wireless signal do not propagate well. In this regard, PLC provides an ideal complement to the Wi-Fi mobile solution by offering PLC Wi-Fi extender products that use the PLC infrastructure as the backbone connecting multiple wireless routers and thus allowing seamless mobility without the need for spectrum sharing Wi-Fi repeaters.

Of course, one could also use dedicated Ethernet and also digital communications over Coaxial cable (Multimedia over Coaxial (MoCA) [6]) or even over the telephone lines (HomePNA [12]). The emerging IEEE 1905.1 standard provides an integrated solution with seamless routing and load balancing over Ethernet, PLC (HomePlug AV), MoCA, and Wi-Fi and promises to provide a well-suited solution for the converged digital home.

PLC is also well suited for Smart Energy applications. Since the energy is electrical in nature, attached PLC devices to the electrical wires delivering the energy are ideal candidates for Smart Grid monitoring, control, and computational optimization applications. Indeed, the “simplified HomePlug AV” (aka HomePlug *Green PHY*) specification directly provides a low-cost Smart Energy solution, ensuring full interoperability with broadband HomePlug AV and IEEE 1901 PLC systems. We can now envision a world where appliances, meters, and other electrical devices have embedded Smart Energy PLC devices that enable a truly intelligent home.

## 1.5 BOOK OUTLINE

Following this introductory chapter, the rest of this book is organized as follows.

Chapter 2 gives an overall description of the HomePlug AV network architecture, delineating the protocol layers in HomePlug AV and how these relate to the standard OSI protocol layers. Special attention is given to the function and role of the HomePlug AV Convergence layer. This chapter also introduces the HomePlug AV network topology, identifying the various station roles and defining the HomePlug AV Local Network (AVLN). With this infrastructure in place, the chapter then proceeds to outline the essentials of peer-to-peer communication, bridging, network membership, and channel access in HomePlug AV networks.

In Chapter 3, the authors take a step back and examine the overall philosophy and reasoning that guided the technology selection in overcoming the challenges of high-speed multimedia communications in one of the harshest communication channels known to man. The frequency and time characteristics of the typical PLC channel are

reviewed with snapshots of real measurements taken to illustrate the enormity of the challenge. The chapter then gives the details of the frequency band selection, the selection of windowed FFT-based OFDM with some commentary on comparisons with other possible technologies, the use of Turbo Convolution Codes (TCC) again with observations about the performance of rival approaches and providing the guiding principles in the selections made. An entire section is dedicated to a discussion of the intelligent channel adaptation schemes used in HomePlug AV, giving details of the bit-loading adaptive modulation scheme adopted and the exploitation of the cyclostationary noise behavior in the AC line cycle-based adaptation and Beacon synchronization especially with a focus on enabling TDMA allocations in HomePlug AV. The chapter also discusses how the two-level segmentation and reassembly scheme used in HomePlug AV yields higher overall efficiency and how this is implemented in the Data Plane. The chapter concludes with an explanation on persistent and nonpersistent schedules for TDMA operation.

Chapter 4 presents the details of the HomePlug AV physical layer protocol, including the preamble used for synchronization as well as the structure of the PHY Protocol Data Unit (PPDU), Frame Control, and Payload. The adaptive Tone Maps used to achieve high-throughput in the PLC channel as well as the associated parameters used for robust (ROBO) communication for critical control-related messages are described. The chapter concludes with a discussion of the Tone Mask used to mitigate interference, the Amplitude Map used to maintain acceptable power levels in each subband, and the overall functional transceiver block diagram.

Chapter 5 is devoted to the MAC Protocol Data Unit (MPDU) and discusses the various types of delimiters and associated variant fields used in HomePlug AV. The structure of the payloads for the Beacon, Data, and Sound frames are presented in detail.

Chapter 6 discusses the HomePlug AV Data Plane, giving specific attention to the segmentation and reassembly strategies used to convert between the MAC Service Data Unit (MSDU) and the MPDU via a PHY Block (PB) used as a basic unit of encryption. The chapter also explains the HomePlug AV queuing strategy for management, broadcast, connectionless and connection-oriented queues, as well as the operation of HomePlug AV Data Plane structures in a multinet network infrastructure.

Chapter 7 takes up the important topic of the operation of the Central Coordinator (CCo) in HomePlug AV, including the CCo selection, backup, and failure recovery, as well as the CCo discovery process. Since the CCo is central to the operation of HomePlug AV, CCo functions are also discussed as needed in other chapters of the book.

Chapter 8 explains the hybrid HomePlug AV CSMA/TDMA channel access mechanisms. It shows how the operation of the Beacon and the Beacon period structure enable the coordination of CSMA access and TDMA access with admission control and persistent and nonpersistent scheduling.

Chapter 9 begins with an overview of the packet classification mechanism that enables HomePlug AV to distinguish the QoS needs of various MSDUs. This is followed by details on connection specification (CSPEC) and the associated connection setup, modification, and teardown procedures that enable the provisioning of parameterized QoS. The role of the CCo in bandwidth management is also explained.

Chapter 10 examines the question of security and network formation in HomePlug AV, from power-on to association, authentication, and authorization. The chapter discusses the various security keys used in HomePlug AV, including the various key entry modes (direct, remote, and push button).

The next three chapters present useful details on the practical functioning of HomePlug AV. Chapter 11 discusses the key HomePlug AV operations of channel adaptation, bridging, coexistence with HomePlug 1.0.1, and Proxy Networking. Chapter 12 covers bandwidth sharing in neighbor networks in HomePlug AV, including the specific cases of CSMA-Only, Uncoordinated, and Coordinated modes. Chapter 13 presents a summary of key management messages used in HomePlug AV.

Chapter 14 provides an overview of the IEEE 1901 standard, with separate sections devoted to the PHY and MAC of the FFT-based realization and the Wavelet-based option. The chapter also discusses the functional elements of the Inter System Protocol (ISP) used to ensure coexistence between FFT and Wavelet IEEE 1901 devices as well as between any IEEE 1901 in-home device and an IEEE 1901 Access device or a G.hn device.

The concluding chapters give an overview of the HomePlug Green PHY specification (Chapter 15) as a simplified HomePlug AV incarnation and the HomePlug AV2 specification (Chapter 16) as an enhancement of HomePlug AV, with MIMO, power save, repeating, delayed acknowledgments, and larger bandwidth, all of which combine to yield a PHY rate of 1.5 Gbps.