

Chapter 16

Communication Methods for Smart Buildings and Nearly Zero-Energy Buildings

Yasin Kabalci

Abstract This chapter presents wired and wireless communication systems in smart homes and smart buildings by considering the recent developments seen in applications. In order to provide further knowledge for readers, the basic principles of the smart homes and energy efficient buildings are firstly introduced. Then, the nearly zero-energy buildings and renewable energy integration in buildings issues are comprehensively explained by taking into account existing applications. In addition, advanced metering infrastructure that is a vital component of the smart home systems is expressed in detail. Afterwards, the potential candidates of communication systems for smart buildings that have an important role to realize nearly zero-energy buildings are discussed by comparing each method and application types thoroughly. These communication systems are classified as wired and wireless communication systems to examine more detailed and the communication systems are compared according to several considerable parameters such as used spectrum, modulation types, bit rates, supported network topologies, media access control (MAC) schemes, carrier types, and application areas. Moreover, several applications of examined communication systems are presented both for outdoor and indoor scenarios.

Keywords Smart homes · Smart building energy management systems (SBEMS) · Advanced metering infrastructure (AMI) · Power line communication (PLC) systems · Wireless communication systems

Abbreviation and Acronyms

AES	Advanced Encryption Standard
AMI	Advanced Metering Infrastructure
AMM	Automatic Meter Management

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AMR	Automatic Meter Reading
AP	Access Point
ARIB	Association of Radio Industries and Businesses
BAN	Body Area Network
BB	Broadband
BP	Belief Propagation
BPSK	Binary Phase Shift Keying
CC	Convolutional Codes
CCK	Complementary Code Keying
COFDM	Coded OFDM
CP	Cyclic Prefix
CSMA	Carrier Sense Multiple Access
CSMA/CA	Carrier Sense Multiple Access/Collision Avoidance
CSMA/CD	Carrier Sense Multiple Access/Collision Detection
D8PSK	Differential 8-Phase Shift Keying
DBPSK	Differential Binary Phase Shift Keying
DCSK	Differential Chaos Shift Keying
DG	Distributed Generation
DMS	Data Management System
DQPSK	Differential Quadrature Phase Shift Keying
DSL	Digital Subscriber Line
EU	European Union
FCC	Federal Communications Commission
FEC	Forward Error-Correction
FFT	Fast Fourier Transform
FSK	Frequency Shift Keying
GFSK	Gaussian Frequency Shift Keying
HAN	Home Area Network
IRRWBF	Implementation-Efficient Reliability Ratio Based Weighted Bit Flipping
ITU	International Telecommunication Union
IWBF	Improved Weighted Bit Flipping
LAN	Local Area Network
LDPC	Low-Density Parity-Check
LLR	Log-Likelihood Ratio
MAC	Media Access Control
MPPT	Maximum Power Point Tracking
NB	Narrowband
OFDM	Orthogonal Frequency Division Multiplexing
OOK	On-Off Keying
OPGW	Optical Power Ground Wire
O-QPSK	Offset Quadrature Phase-Shift Keying
P&Q	Perturb and Observe

PAM	Pulse Amplitude Modulation
PAN	Personal Area Network
PLC	Power Line Communication
PPM	Pulse Position Modulation
PV	Photovoltaic
QAM	Quadrature Amplitude Modulation
QPSK	Quadrature Phase Shift Keying
RS	Reed Solomon
SBEMS	Smart Building Energy Management Systems
S-FSK	Spread Frequency Shift Keying
SM	Smart Meter
SS	Spread Spectrum
TDD	Time Division Duplexing
TDMA	Time Division Multiple Access
THD	Total Harmonic Distortion
WAN	Wide Area Network
WBF	Weighted Bit Flipping
WLAN	Wide Local Area Network
WM-Bus	Wireless M-Bus
WPAN	Wireless Personal Area Network
WSN	Wireless Sensor Network

16.1 Introduction

The smart grid is defined as the integration of information, telecommunication, and network technologies in order to provide the conventional grid more reliable and more controllable. The mentioned integration provides several advantages such as more automation in daily life and industry, security of electric services, increased life-time of home appliances, and increasing the comfort of consumers. Owing to the improvement of smart grids, various developing methods and technologies have been reported in past decade by researchers across the globe. The most widely known technologies among them are smart meters (SMs), advanced metering infrastructure (AMI), home automation, bidirectional communication, and home area networks (HANs). The conventional electric power grid has been serving more than one century. The increasing and varying consumer profile depending to the increased population requires the conventional grid to supply electrical devices more than ever that causes instability of the electric power grid. The applications of the smart grid include generation, transmission, distribution, and consumption of electrical energy. The most important advance provided by the smart grid during the generation is to enable the distributed power generation, where power can be generated locally; to use the required energy and sale excess power back to utility.

In transmission and distribution applications, the smart grid enables electric providers to increase control capabilities by improving the reliability, stability, and sustainability of the system. Therefore, it is also demonstrated that economic and social benefits can be provided by consuming electrical energy efficiently. The smart building energy management systems (SBEMS) increase the efficient consuming, and any consumer can reduce the energy bill and decrease peak demand.

In recent years, the home environment has been rapidly converted to network enabled digital technologies. This improvement enabled the home appliances to increase the connectivity within the buildings for the purpose of home automation in novel and exciting opportunities. Power line communication (PLC) systems and mobile devices increase their communication speeds due to their portability and their wide range of capabilities. Hence, this chapter intends to comprehensively describe the communication methods for smart buildings that have an important role to realize nearly zero-energy buildings. The distributed generation (DG) that is one of the basic features of smart grids can be enabled to integrate to the management system to allow consumers to manage renewable energy sources such as solar panels and wind turbine, electric vehicles and energy storage system comprised of batteries that may be included in the energy infrastructure of the buildings. Thus, the SBEMS permits consumers to decrease the energy consumption and bill costs owing to the renewable energy sources that are controlled by the SBEMS besides security, illumination, heating, and multimedia system controls. The main features of the SBEMS are online control capability, renewable energy integration and consumption control, the charge amount of energy storage system, listing of monthly energy consumption rates saved bill costs, wireless monitoring and management system, and user interface to control home appliances. The communication methods utilized for the smart buildings and nearly zero-energy buildings can be classified into two categories as wired and wireless communication systems. The PLC system provides an efficient communication scheme for transmitting and receiving any type of data by employing existing power lines. In addition, the PLC system presents an inexpensive and suitable communication channel for data transmission and is a potential candidate in many application areas such as smart homes, vehicles, home automation systems, smart grids and so on. On the other hand, the wireless technologies such as Bluetooth, ZigBee, Wi-Fi can be utilized in the smart buildings alternatively. In this chapter, emerging communication technologies, advanced design and modeling studies on nearly zero-energy buildings are comprehensively discussed.

16.2 Smart Homes and Energy Efficient Buildings

Smart home term can be defined as the integration of technology and services in order to present for a better quality of living, where the transmission of information is provided by means of home networking. This technology offers several features to users such as connecting, controlling and monitoring home appliances and



Fig. 16.1 The concept of smart home systems

performing the functions with respect to predefined conditions. These features can be accomplished with communication systems of the smart homes based on the internet, mobile phones and PLC systems. In addition, developments on sensor technologies, embedded systems and communication systems have enabled the control of the smart homes in an easy and manageable way [1]. A smart home concept is shown in Fig. 16.1.

The smart homes that offer flexibility and functionality advantages require an energy management system called the SBEMS to provide economic and social benefits to users. In addition to conventional home management systems, the SBEMS controls the DG that is one of the basic features of smart grids, renewable energy sources and the interaction of electric vehicles with homes. The technical background of the SBEMS can be classified into two categories as home management system and energy management system. The home management system contains the control of electrical appliances used by the user's daily life and is concerned with user's comfort and other necessities. For instance, it comprises control of illumination, heating, cooling, multimedia systems and electrical household appliances. The second part of the SBEMS, which is the energy management system, includes details that are more technical. The DG systems of the renewable energy sources such as wind turbine and solar panels, support units of

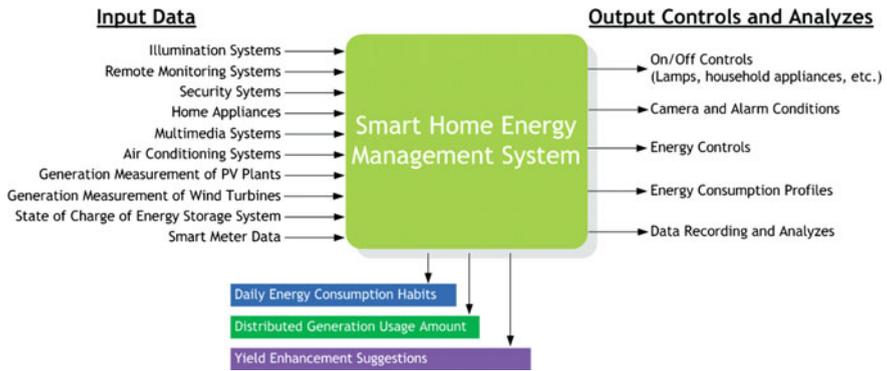


Fig. 16.2 Control and interface infrastructure of the SBEMS

these systems such as energy conversion and storage systems and the integration of electric vehicles can be utilized more efficiently owing to the energy management features of the SBEMS. A control and interface infrastructure diagram of the SBEMS is illustrated in Fig. 16.2.

The main features of SBEMS given in the Fig. 16.2 can be summarized as renewable energy integration, energy consumption control, the charge amount of energy storage system, online control capability, listing of daily, weekly or monthly energy consumption rates to save bill costs, communication capability for monitoring and management system, and user interface to control home appliances. Input data of the SBEMS that are shown on the left side of the Fig. 16.2 are transferred to the energy management system to inform users about actual status of the building. On the other hand, the right side of the figure indicates output controls and analyzes that can be carried out by the users. For instance, on/off control system contains basic level controls for starting or stopping commonly used electrical appliances and devices such as lamps, television, washing machine, refrigerator, air conditioning and so on.

In recent years, the development of internet technology has led to social and economic developments. Depending on the rapid spreading of wireless internet, people can take advantage of internet technology even if they are outdoors and are able to follow their all activities. Furthermore, the interaction between internet and daily family life has enabled the creation of the infrastructure for smart home technologies. Internet based management systems can be provided remote control for electrical household appliances to form intended comforts before the users reach home. In addition to this, the conducted investigations shown that hard-working people did not take the time to track these systems and they considered the tracking process as a waste of time. Therefore, some of the users also expect that the system is able to track the situation automatically and able to predict or remember user's habits according to the user's requests [2–5]. Although these demands are noted among the features of the home management system, the smart home management

systems used in the Far East and the United States carry out the management of the home, by recognizing the user's behavior, according to the user's habits rather than simply fulfill the user's commands.

16.3 Nearly Zero-Energy Buildings and Renewable Energy Integration in Buildings

Energy efficiency has become an important issue since energy consumption has been increased throughout the world in recent years. The decreasing fossil fuels directed governments to encourage use of the renewable energy sources and to draw attention to the energy efficiency. Recently, researchers have made many studies on the energy efficiency. Tascikaraoglu et al. [6] has presented a study on the concept of smart home and energy efficiency by examining the structure and requirements of the smart grids. According to this study, the smart homes that use the production and transmission characteristics of smart grids can provide energy savings between 10 and 30%. It is also emphasized in the study that user habits on this ratio are highly effective [6–8]. In addition, it is important to note that the SMs, energy management system and user habits should be considered to obtain energy savings in the specified ratio [8]. In [9], Missaoui et al. has reported that intensive researches, which are mostly carried out considering the consumption side have been done on the smart grid technology and load control issues in the last 2 years. The total energy consumed at homes corresponds to 32% of the total amount consumed in the world according to results of this study. At the same time, 36% of the carbon emissions occurred in the European Union (EU) countries is caused by the homes. Within the scope of the EU's climate and energy policy, not only the energy performance but also load management in the homes has been identified as an important issue and was included in the 2020 plans [9, 10]. Moreover, a building energy management system is designed to control an electric kettle, heating, cooling, ventilation system and thermodynamic system in [9]. Research results shown that home appliances such as the heater, washing machine, dishwasher and refrigerator caused by 80% of energy consumption resulting from home. Mahmood et al. [11] realized a study based on demand response and consumption side of energy management similar to previously mentioned work. For this purpose, they focused on linear programming and developed an optimization algorithm to reduce the power consumption at homes. They built an infrastructure enabling the use of smart devices for smart home energy management and called this system as "home appliances coordination scheme". Capitanelli et al. [12] also proposed another simulation model for smart home management system, where authors utilized this simulation model to manage household appliances in terms of performance and energy consumption. Accordingly, the proposed method is carried out in six stages. In the first two stages, users' requirements are determined and these requirements are defined as the smart home functions. The third stage covers classification and

identification operations of the household appliance characteristics. In the following stage, a general information management model is created. After defining the rules and tasks for intelligent system, service functions are performed and are stored in the last stage.

In another study, the most widely used devices in the homes and their usage rates are investigated as a special case study for the Canada [13]. According to this work, the most widely used home devices are heating systems, refrigerators, electric cars, washing machines, dishwashers and lighting systems in terms of electricity consumption. In addition, the 45.6% of homes do not have the stereo system whereas there is at least one at 43.2% of them. The obtained results shown that annual energy consumption results are 19.3 MWh for heating devices, 5.5 MWh for water heaters, 3.6 MWh for electric cars, 1.364 MWh for washing machines and dryers and 1.277 MWh for lighting systems. The communication systems used in home management systems are indicated as Wi-Fi, WiMax, 3G, DSL, Ethernet, ZigBee and fiber optics. The ZigBee that is one of the mentioned communication methods is employed on an energy management system reported by Batista et al. [14]. Although many communication technologies are appropriate, the ZigBee is preferred in this study due to low power consumption in wireless communication protocols and suitability to the control and monitoring applications. In studies about the SMs conducted from 2009 to 2015, the ZigBee has become rapidly widespread and showed an increase of 35%. Therefore, authors establish a ZigBee communication platform to monitor renewable energy grid consisting of wind and solar energy. In [15], Al-Ali et al. have proposed a GSM based energy management system for smart homes integrated with renewable energy sources.

It is understood from these studies that a large number of the existing homes over the world and energy-consuming devices in these buildings increase the energy demands excessive. However, decreasing of fossil fuels requires efficient use of available energy sources and ensuring energy efficiency as soon as possible. The main legislations of the EU are the 2010 Energy Performance of Buildings Directive (2010/31/EU) and the 2012 Energy Efficiency Directive (2012/27/EU) and these legislations are aimed to reduce energy consumption in the buildings. These legislations are also intended to ensure all new buildings to be nearly zero-energy buildings by 2020. At this point, the commission defines nearly zero-energy buildings as follow: Nearly zero-energy building is a building that is capable of a very high-energy performance. The required low amount energy should be provided from renewable energy sources which are constructed on-site or nearby of these buildings.

16.4 Advanced Metering Infrastructure (AMI)

The smart metering systems that are composed of measurement and monitoring process are intended to provide information to users about energy consumption of the smart homes. The acquired data are mapped with respect to utilized

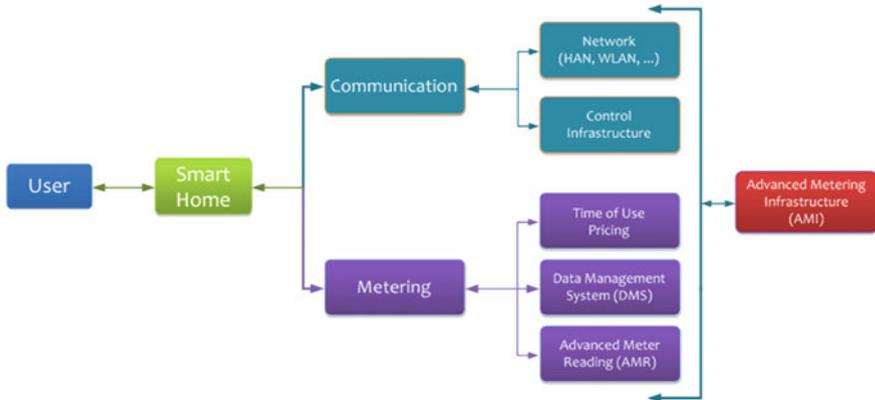


Fig. 16.3 The components of the AMI system in the smart homes [18]

communication protocol standards and are conveyed to management system over wired or wireless communication networks. The AMI system could be considered as an improved type of the conventional automatic meter reading (AMR) and automatic meter management (AMM) systems since it includes various developed technologies such as the SMs, HANs, wide area networks (WANs) or neighbored networks [16, 17]. The smart measurement process can be carried out by employing a SM that computes the energy consumption of any smart home. Hence, the SMs should have the ability to determine energy consumption rates of the smart homes in real-time by measuring parameters such as voltage, current, phase angle and frequency. A smart metering system involved in the metering and communication infrastructures is depicted in Fig. 16.3.

As can be seen from the figure, the metering section of the SM contains time-of-use pricing control system, data management system (DMS), and AMR framework. Wired or wireless communication techniques can be used in the communication part of the smart metering system. The communication substructure should permit a two-way data flow between smart homes and users. Therefore, network connection and control substructure are also required in the communication part of the SM. In addition to these two main sections, the SM modules may contain power supply module, timing module, indicating module, and encoding module. Besides, the SMs control the energy demand of the user by restricting consumption. It is noteworthy that the SMs will cover important roles in the future of the smart home applications due to their real time management, scalability, and security features. It is important to note at this point that the use of the access point architecture is also required to communicate with several hundreds of the SMs in an area. Therefore, the security issue should be taken into account for preserving measurement information in the SMs.

16.5 Wired Communication Systems for Smart Buildings

The most significant advantages provided by wired communication systems are reliability and insensitivity to interference. While the PLC systems utilize conventional power lines, fiber optic and digital subscriber line (DSL) systems use telephone lines as a communication medium. The capability of transmitting Gbps data packets to several kilometers and ability of strength against electromagnetic interference are the most important advantages of optical communication systems [19, 20]. The optical communication systems can be used over high voltage power lines due to these advantages. Moreover, optical power ground wire (OPGW) cables that are a special type of optical cables are able to transmit high capacity data over long distances. The DSL systems, which permit to transmit digital data by telephone lines can be utilized as a wired communication technology in smart homes. High-speed data transmission can be accomplished by using digital communication methods. For instance, while the DSL systems provide up to 10 Gbps data rates, coaxial and fiber optic cables reach between 155 Mbps and 160 Gbps data rates [19, 21, 22].

Recently, the PLC systems have gained a great deal of attention in the field of communication, smart grid and home automation systems. These systems provide an efficient communication scheme for transmitting and receiving any type of data, voice, and internet by using existing power lines [23–29]. When the PLC systems are compared with the other communication systems, the most important advantage offered by the PLC systems is obvious that there is no need to construct a new communication medium because of the fact that they utilize the current power lines to convey any type of data. Generally, the PLC applications can be classified into two categories as indoor and outdoor in terms of their application types. The most remarkable outdoor applications of the PLC systems are the smart grids that intent to accomplish several processes of conventional and renewable grids such as remote sensing, measurement, monitoring, and control in a maintainable and trustworthy way [20, 27, 28]. In addition, attention paid to this system is growing owing to numerous reasons such as the DGs, energy planning, remote monitoring and demand prediction issues. On the other hand, indoor applications of these systems aim to ensure high-data rate communication benefits for homes and offices.

The PLC systems can utilize different frequency bands called as narrowband (NB) and broadband (BB) according to types of applications. In addition, many national and international organizations are started to define standards for countries. These standards aim to identify substantial criteria such as types of modulation, bandwidth, channel and source coding schemes, operating frequency and limits of electromagnetic compatibility for indoor and outdoor applications of the PLC systems. In general, it can be noted that while the BB PLC systems ensure high data rates thanks to wide bandwidth, the NB PLC systems are preferable in low-data rate applications such as remote data acquisition, AMR systems, remote fault localization and fault type recognition. The NB PLC standard utilized in Europe exploits between 3 and 148.5 kHz frequency band with respect to European CENELEC

Standard EN50065. Furthermore, the NB PLC standards of the U.S. and Japan are 9–490 kHz in accordance with Federal Communications Commission (FCC) and 10–450 kHz with respect to Association of Radio Industries and Businesses (ARIB), respectively [30]. On the other hand, while the operating frequency of the BB PLC is proposed between 2 and 50 MHz according to the IEEE 1901-2010 standard, the International Telecommunication Union (ITU) recommends between 2 and 100 MHz frequency band. The standards, technical specifications and application areas for the BB and NB PLC systems are given in Tables 16.1 and 16.2, respectively.

16.5.1 Outdoor Application Examples for the PLC Systems

Several SG examples for outdoor application of the PLC systems are given in this subsection. First example deals with the feasibility of the PLC systems in renewable energy generation system modeled in Matlab/Simulink [32]. The aim of this system is to demonstrate that the electrical power lines are not only utilized to carry line voltages but also to transmit several measurement data of the renewable energy grids. Thus, monitoring costs can be reduced by using the reported technique rather than the SCADA, Ethernet or GSM based systems. The main parts of the designed system in the Matlab/Simulink are the photovoltaic (PV) panels, boost converter with perturb and observe (P&O) control algorithm, full bridge inverter, coupling circuits and the binary phase shift keying (BPSK) modem that is exploited to transmit measured data over the power lines. The block diagram of the system is depicted in Fig. 16.4.

As can be seen from the block diagram, the BPSK modulator structure is connected to the output of the full bridge inverter to employ power lines as a communication channel. The modulator aims to convey output power information of the PV panels over the 10 km transmission line which is also modeled in Matlab/Simulink depend on the PI section line model. A coupling device usage is also required in order to combine the BPSK modems with transmission lines. The BPSK demodulator structure is established at the end of the transmission line to acquire the output power information of the PV panels at the monitoring center.

Figure 16.5 shows obtained results for modeled remote monitoring system where two different scenarios are considered in terms of filtering circuit utilized in the BPSK demodulator structure. The cut-off values of the filter are set to 250 Hz and 4 kHz in the performed simulations. The fine filtering term is used for the 250 Hz filter that provides better performance as can be shown from the Fig. 16.5b. While the first curves given in Fig. 16.5 show the measured output data of the PV panels, the second curves depict the quantized data signals of the BPSK modulator. The demodulated data acquired from the output of the BPSK demodulator are given in the third curves and the filtered and calibrated data are shown in the fourth and

Table 16.1 Standards, technical specifications and applications of the BB PLC systems [31]

Technology/standard	Spectrum	Modulation/coding	Bit-rate	MAC	Carrier
HomePlug AV	2–28 MHz	OFDM (1536 tones)	200 Mbit/s	TDMA-CSMA/CA	Multiple
		Bit-loading up to 1024-QAM/convolutional, Turbo codes			
HomePlug Green PHY	2–28 MHz	OFDM (1536 tones) QPSK	3.8–9.8 Mbit/s	CSMA/CA	Multiple
HD-PLC	2/4–28 MHz	Wavelet OFDM (512 tones)	190 Mbit/s	TDMA-CSMA/CA	Multiple
		Bit-loading up to 16-PAM/RS, convolutional, LDPC			
IEEE P1901	2–28 MHz	OFDM (HPAV) (3072 tones)	540 Mbit/s	TDMA-CSMA/CA	Multiple
		Bit-loading up to 4096-QAM			
	2–60 MHz	W-OFDM (HD-PLC) (1024 tones) Bit-loading up to 32-PAM			
ITU-T G.hn ITU-T G.9960	PLC, Coax, phone line: up to 100 MHz (BB) PLC: 100–200 MHz (PB) Coax: up to 100 MHz (PB, Fc = 0.35–2.45 GHz)	OFDM (up to 4096 tones)	>200 Mbps up to 1 Gbps	TDMA-CSMA/CA	Multiple
		Bit-loading up to 4096-QAM/LDPC			

Table 16.2 Standards, technical specifications and applications of the NB PLC systems [31]

Technology/standard	Spectrum	Modulation	Bit-rate	MAC	Carrier	Application
Insteon/proprietary	CENELEC C	BPSK	2.4 kbps	–	Single	Home automation
Konnex/EN50090 EN13321-1 ISO/IEC14543	CENELEC B	S-FSK	1.2 kbps	CSMA	Single	Home automation
X10/proprietary	CENELEC B	PPM	50 or 60 bps	CSMA/CD	Single	Home automation
CEBus/EIA-600	CENELEC C, FCC, ARIB	SS	8.5 kbps	CSMA/CD	Single	Home automation
UPB/proprietary	CENELEC A	PPM	240 bps	–	Single	Home automation
HomePlug C&C/HomePlug consortium	CENELEC A, C, FCC, ARIB	DCSK	0.6–7.5 kbps	CSMA/CA	Single	Command and control
Meters and more/proprietary	CENELEC	BPSK	Up to 4800 bps	–	Single	Advanced metering infrastructure
G3-PLC/ERDF	CENELEC A, FCC	OFDM DQPSK DBPSK	34–240 kbps	CSMA/CA	Multiple	Advanced metering infrastructure
PRIME/prime alliance	CENELEC A	OFDM D8PSK DQPSK DBPSK	128 kbps	CSMA/CA TDMA	Multiple	Advanced metering infrastructure
G.Hnem ITU-T 9955	CENELEC A, B, C, D, FCC	OFDM QPSK 16-QAM	up to 1 Mbps	CSMA/CA	Multiple	Advanced metering infrastructure
IEEE P1901.2	CENELEC A, B, C, D, FCC	–	–	–	Multiple	Advanced metering infrastructure

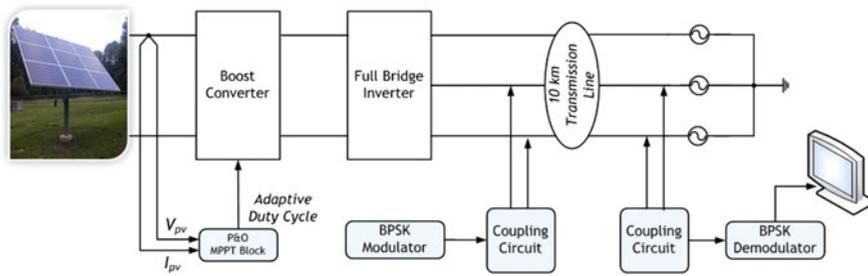


Fig. 16.4 Block diagram of the PLC system with BPSK modem for the PV panels [32]

fifth curves, respectively. When the reported results in the Fig. 16.5a, b are compared, it is clearly shown that the filtering process has an important effect on the performance of the system. It is important to note that even though the modulated data of the output power information are embedded into the grid, there is no distortional effect in the power line and the total harmonic distortion (THD) values of the system are in the suitable ranges according to IEEE-519-1992 and IEC-61000 standards.

An improved PLC system model is presented as the second application where the Quadrature Phase Shift Keying (QPSK Quadrature) modems are designed to create the PLC infrastructure. The modeled energy monitoring system in Matlab/Simulink is shown in Fig. 16.6. First part of the model is the solar plant which is constituted by regarding 170 W commercial solar panels.

In addition, the solar plant contains parallel-connected PV panels with the capability of maximum power point tracking (MPPT) algorithm. While the converter output of the modeled system is fed to a three-phase IGBT inverter, generated AC output voltages are delivered to the grid over 10 km transmission line that are created in accordance with practical parameters. The QPSK modems which are located at the plant side and grid side are utilized to monitor generated power by the solar plant. In addition, coupling devices are employed to prevent information losses due to any mismatch.

Different measurement results of the energy monitoring system are depicted in Fig. 16.7a, b. While cutoff frequency of used low pass filter in the QPSK modem is adjusted as 500 Hz in the Fig. 16.7a, the cutoff frequency is set to 250 Hz in another condition given in the Fig. 16.7b. As can be seen from the measurement results, the 250 Hz filtering provides better performance according to the 500 Hz filtering. As a final remark, the introduced results shown that use of the QPSK modems in the PLC applications to monitor energy plants can provide more accurate results according to use of the BPSK modem.

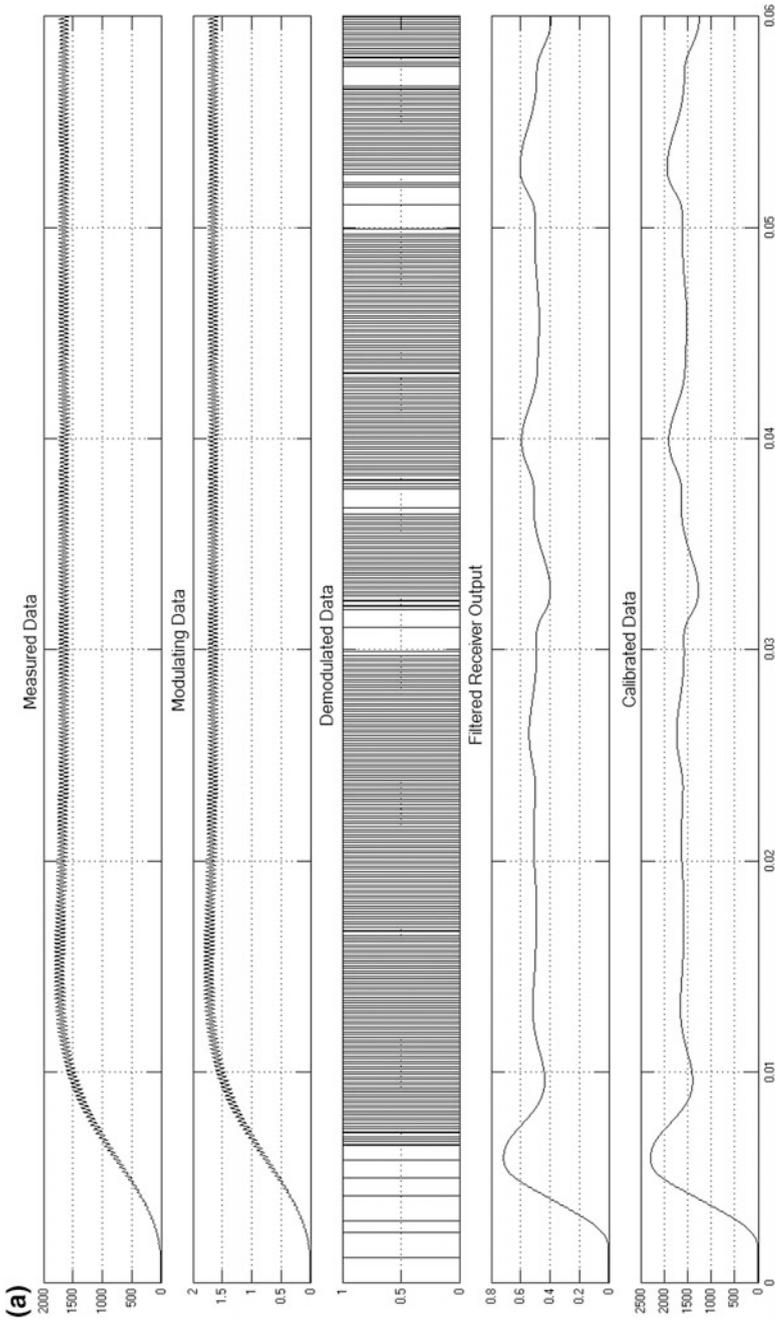


Fig. 16.5 Simulation results of the reported system with the BPSK modem: **a** Coarse filtering. **b** fine filtering [32]

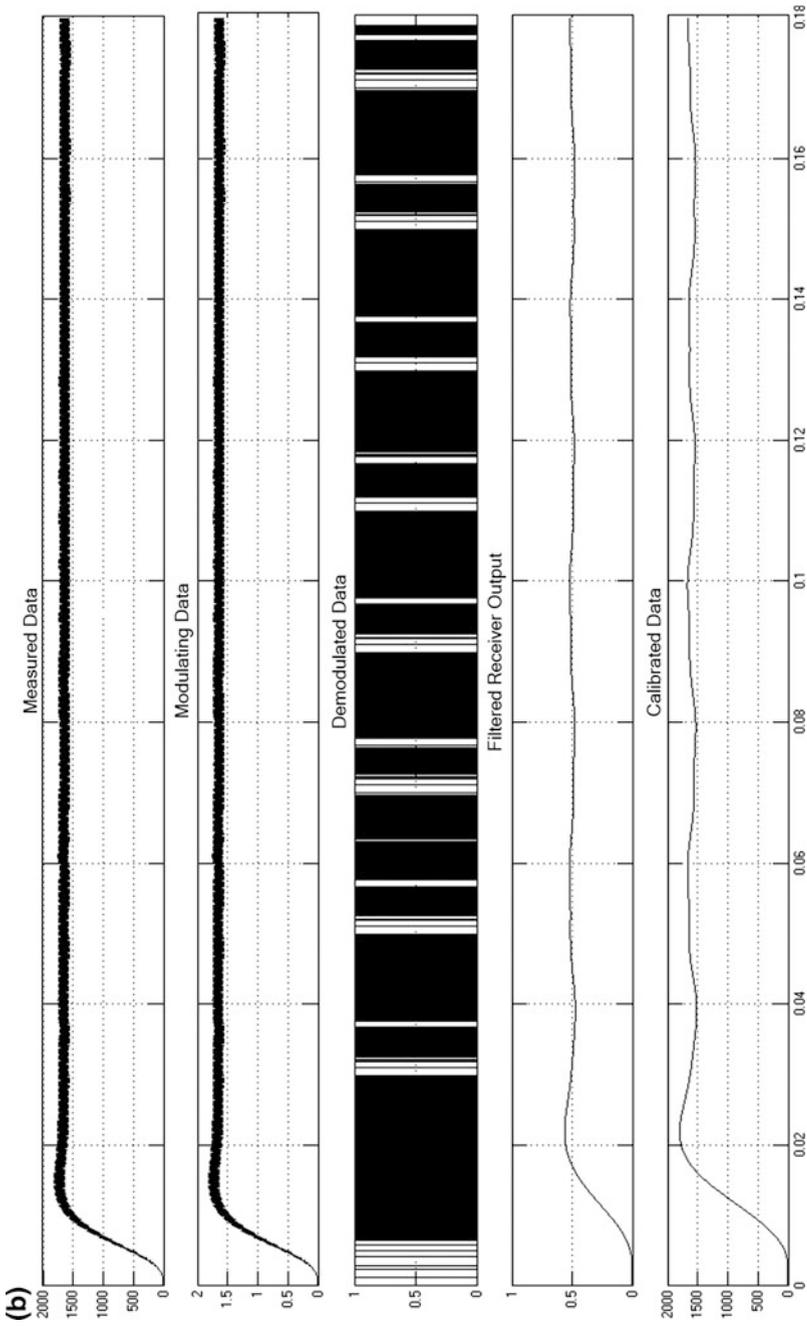


Fig. 16.5 (continued)

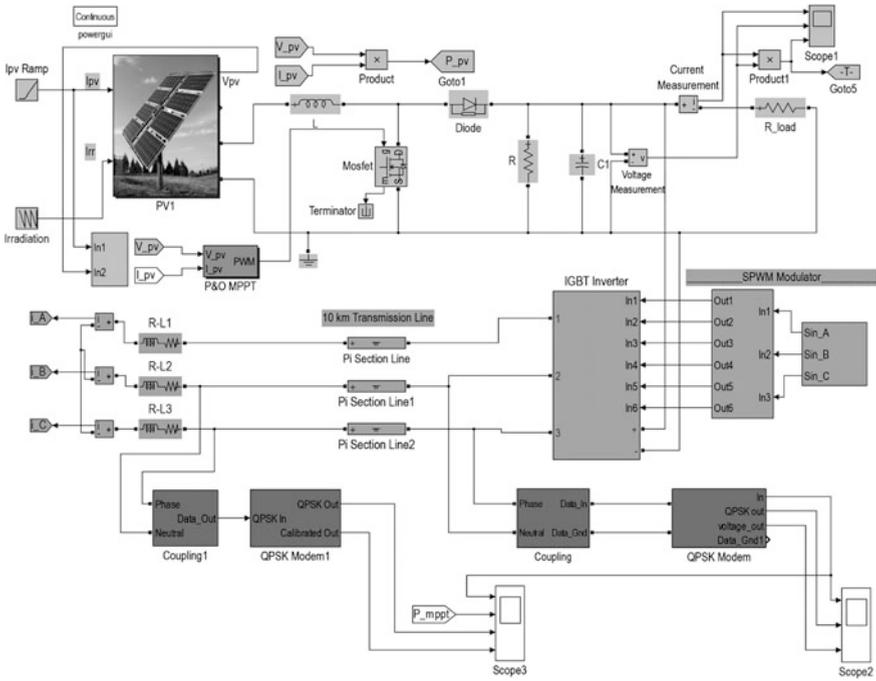


Fig. 16.6 Matlab/Simulink design of the energy monitoring system with QPSK modem [27]

16.5.2 Indoor Applications for the PLC Systems

In this subsection, different applications of the PLC systems for indoor environments are presented. The PLC system can be utilized to transmit data, which may be acquired information from any sensor located in the smart buildings, over indoor PLC channels. On the other hand, since the power lines have been fundamentally designed to deliver electricity over the world, they exhibit a destructive channel effect for communication signals. Hence, transmitting high frequency communication signals over actual power lines is a difficult problem and the PLC channel need to be accurately characterized to solve this problem. A BB indoor PLC channel model was reported by taking into account of a realistic network infrastructure for homes and small offices in [33].

In this PLC channel model, structural features of building electricity network are considered to characterize the indoor PLC channel in terms of network scheme, employed cable types, and loads connected to the grid. Furthermore, this model offers more appropriate channel conditions in point of the attenuation, delay spread and average channel gain. Thus, this PLC channel model is exploited to create indoor PLC channel conditions in the application examples presented in this subsection.

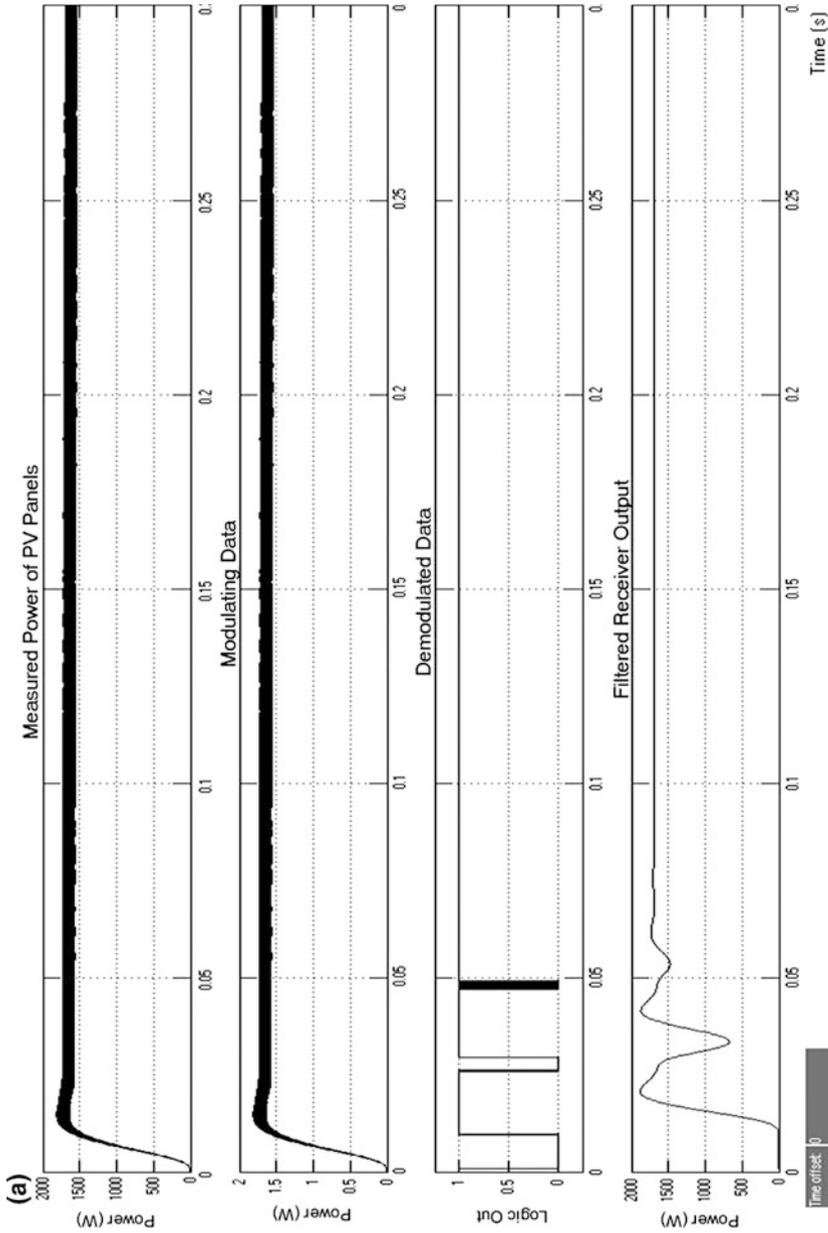


Fig. 16.7 Results of energy monitoring system: **a** QPSK modem with 500 Hz cutoff frequency filter, **b** QPSK modem with 250 Hz cutoff frequency filter [27]

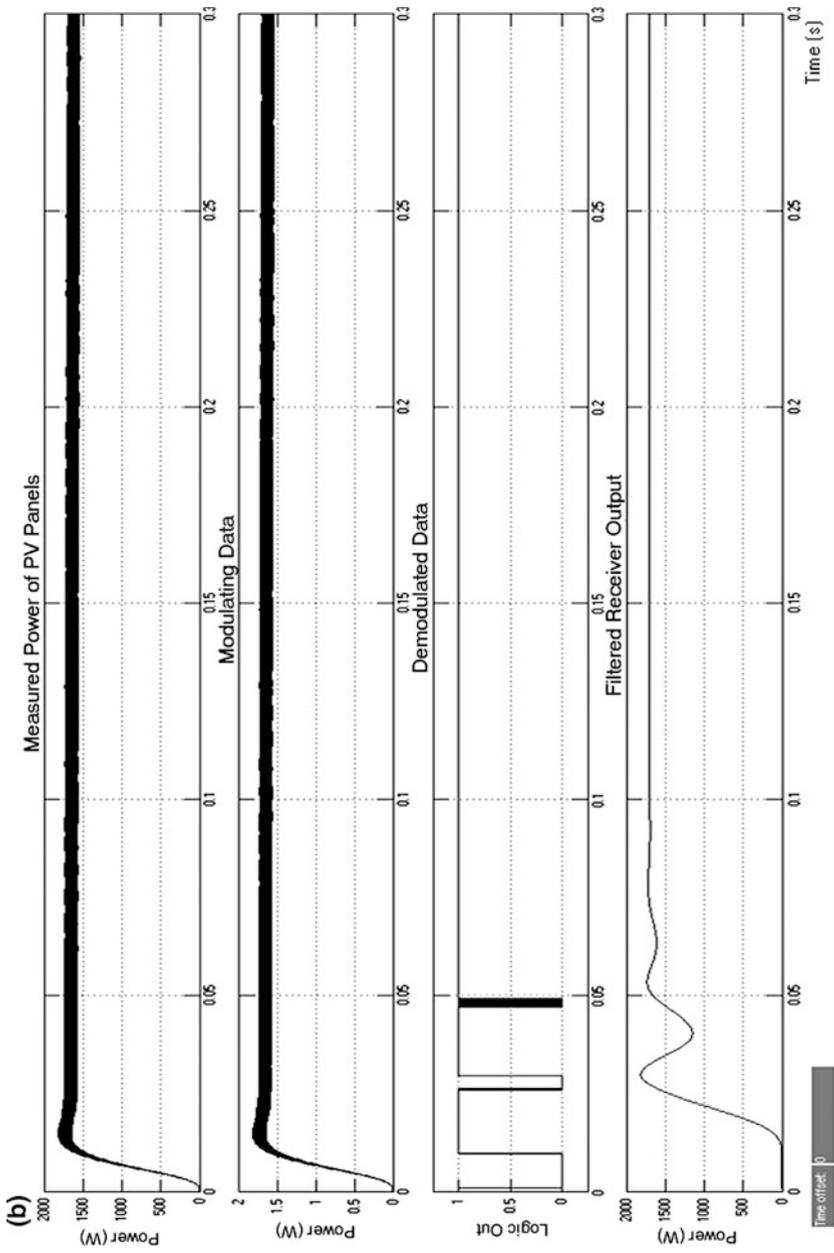


Fig. 16.7 (continued)

Table 16.3 Parameters of computer simulation exploited to evaluate BER performances [34]

Parameter	Value
Block numbers	1000
Size of parity-check matrices	(273,191), (495,433)
LDPC code rates	0.3, 0.125
LDPC decoder schemes	BP, WBF, IWBF, IRRWBF
Convolutional code rate	1/3
Convolutional code decoder	Hard decision Viterbi decoder
Maximum iteration number	30
Modulation type	BPSK
Channel model	Canete's PLC channel model
Noise types	Background and impulsive

In order to evaluate the bit error rate (BER) performances of different channel coding schemes, several computer simulations over the BB PLC channels are performed in [34]. Since low-density parity-check (LDPC) codes and convolutional codes (CC) are widely exploited channel coding codes in the communication systems, their performance comparison is presented when they are utilized as channel coding schemes in the indoor PLC channels. Two different-rate LDPC codes are tested to determine effect of the code rate on the performance of the communication systems. In addition, different soft and hard decision LDPC decoder schemes such as belief propagation (BP), implementation-efficient reliability ratio based weighted bit flipping (IRRWBF), improved weighted bit flipping (IWBF) and weighted bit flipping (WBF) decoders are considered in realized simulations. Simulation parameters of the designed communication system are given in Table 16.3.

The performance results of the LDPC and CC coded communication systems in terms of BER versus E_b/N_0 value are shown in Fig. 16.8. While (273,191) LDPC codes are selected in the Fig. 16.8a, (495,433) LDPC codes are used in the Fig. 16.8b. As expected from the disruptive effects of the indoor PLC channels, communication systems cannot supply an acceptable performance up to 15 dB E_b/N_0 value for both results. When this E_b/N_0 point is exceeded, performances of the LDPC decoders are increased rapidly. As can be seen from the Fig. 16.8a, b, the best performance result is provided by the BP decoder scheme for both results. The supplied coding gains by this decoder scheme are as much as 18 dB for a BER of 10^{-2} and 17 dB for a BER of 10^{-1} as seen in Fig. 16.8a and b, respectively. Though the worst BER performance among the other LDPC decoders is presented by the IWBF decoder scheme, it provides up to 9 dB better performance than that of the CC at a BER level of 10^{-2} . The simulation results shown in the Fig. 16.8a, b clearly indicate that the BP decoder scheme presents best performance results because of using log likelihood ratio (LLR) for decision procedure. On the other hand, decoding complexity of the BP decoders is too high. However, WBF and IWBF decoders, which are hard decision decodes as mentioned before, offer

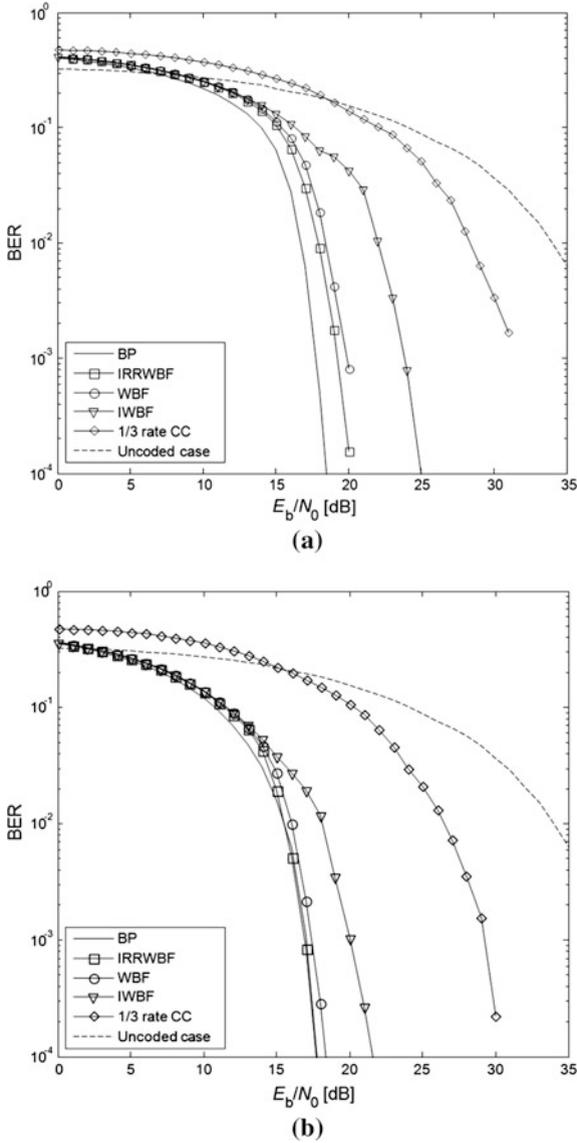


Fig. 16.8 The BER performance comparison of coded and uncoded systems in the BB PLC channel conditions: **a** Performance results for (273,191) LDPC codes, CC and uncoded case, **b** performance results for (495,433) LDPC codes, CC and uncoded case [34]

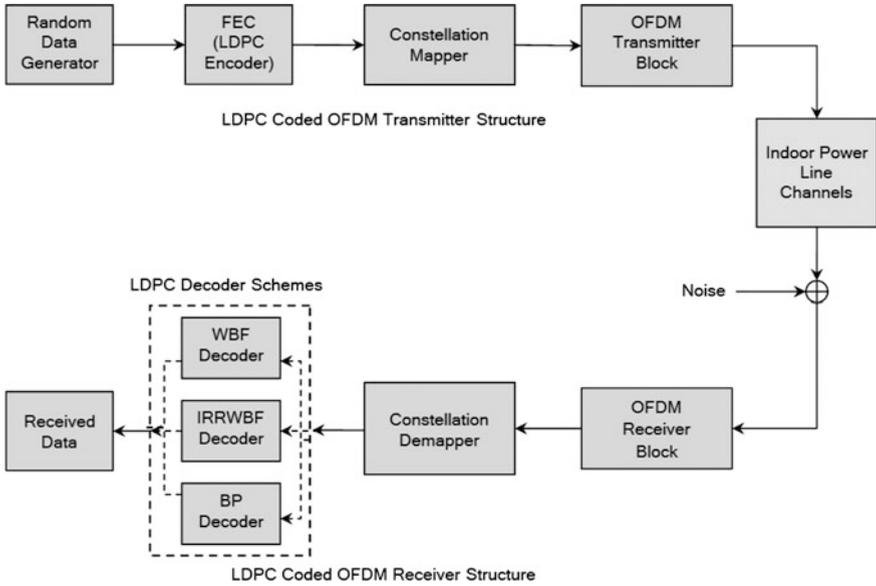


Fig. 16.9 The LDPC coded OFDM system with different decoder structures in indoor PLC channels [35]

tradeoff advantage between error correction and decoding complexity. In addition to reduce decoding complexity, IRRWBF decoders ensure very valuable performance on the error correction.

The BER performances of LDPC coded orthogonal frequency-division multiplexing (OFDM) systems are investigated in another indoor PLC application. This example aims to examine effects of the LDPC decoder schemes on the system performance which is evaluated over the BB PLC channels provided by Canete [33]. The block diagram of the LDPC coded OFDM system with different soft and hard decision decoder schemes is illustrated in Fig. 16.9.

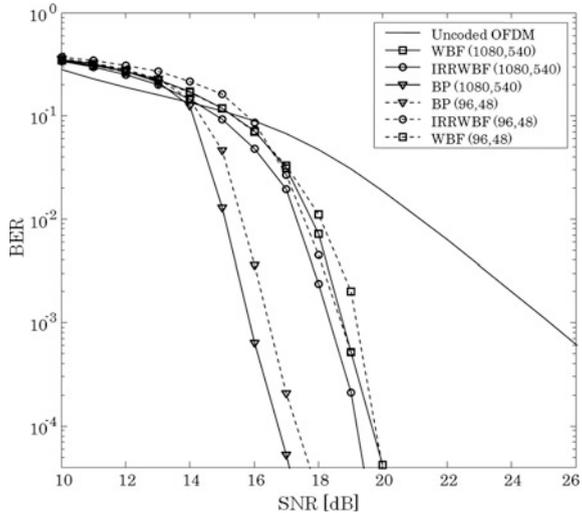
The upper part of the block diagram shows transmitter of the LDPC coded OFDM system. Even though input message of the communication system is generated by random data generator block, the input message can be also supplied from any sensor located in homes or buildings. Later, input message is fed to forward error-correction (FEC) block where the LDPC encoder block fulfills channel-coding process. The constellation mapper block applies the mapping process, in other words modulation process, to the LDPC coded input data. In OFDM transmitter block, several important processes such as pilot symbol insertion, cyclic prefix (CP) adding and parallel to serial conversion are conducted and then coded data are sent to the indoor PLC channels. Several disruptive effects such as noise and attenuation that are originated by the characteristics of the power lines impress the data sent to the indoor PLC channels. The noise shown in these channels is composed of the background noise, impulsive noise and narrowband interferences. The underside of

the block diagram denotes the receiver part of the communication system. In the first block of the receiver part, the input serial data are firstly transformed to parallel data type and then the CPs of the data are cancelled in order to perform fast Fourier transform (FFT) process. After the FFT process, pilot symbol removal and demodulation process are respectively applied to the data. The last step of the receiver unit is decoding process, which can be implemented by employing soft or hard decision decoders.

In simulation carried out by using Matlab software, the LDPC codes with (96,48) and (1080,540) code lengths are exploited to obtain the BER performances of the modeled communication system. While the BP, WBF and IRRWBF decoders are utilized in the simulation, the maximum iteration number is adjusted as 50 for entire decoder schemes. In addition, the subcarrier space and CP of the modeled OFDM system are established as 468.75 kHz and 0.53 μ s, respectively. The BER performance results of coded and uncoded OFDM systems in indoor PLC channels are illustrated in Fig. 16.10.

It is clearly seen from the figure that the LDPC coded OFDM systems outperform with regard to the BER performance than that of the uncoded OFDM system. The BER of (96,48) LDPC coded OFDM system shows virtually 9.5 dB better performance according to the uncoded system at a BER level of 10^{-3} . Furthermore, the (1080,540) LDPC coded system demonstrates 0.7 dB better performance results with respect to (96,48) LDPC coded system with BP decoder. When the performances of the WBF and IRRWBF decoders are considered, it is obvious that the IRRWBF decoder scheme ever provides approximately 0.5 dB better performances. In addition, it is detected that the hard decision decoder schemes present as well as 7.5 dB performance improvement at a BER level of 10^{-3} with respect to the uncoded OFDM communication system.

Fig. 16.10 The LDPC coded OFDM system with different decoder structures in indoor PLC channels [35]



16.6 Wireless Communication Systems for Smart Buildings

The wireless communication systems are one of the most powerful candidates in smart homes. Despite offering several advantages in terms of installation and coverage, the main problems of the wireless systems are reflection, diffraction, scattering and multipath propagation. Since the local area network (LAN), body area network (BAN) and personal area network (PAN) are generally utilized to create small area networks, they can be also employed to define HAN in the smart homes and nearly zero-energy buildings. Low-cost local network applications are generally exploited these network schemes. The HAN, which is formed to realize energy management and demand planning has a small coverage area with low latency advantage. In addition, the wireless networks contain hierarchical mesh networks thanks to wireless LANs to interact with electrical home appliances. On the other hand, wireless sensor networks (WSN) can be also used as an alternative cost effective solution in the smart homes owing to their low energy requirements.

The wireless PAN (WPAN or IEEE 802.15.4 standard) intends to define the PHY layer for low data rate, low power consumption, and low-cost network. The basic PHY layer of the WPAN ensures 256 kbps data rate in the coverage area, which covers between 10 and 1600 m in the star topology for single-hop, cluster-tree, and mesh topology for multi-hops. In order to control the entire network, a PAN coordinator is placed in each type of the topology. Moreover, mesh and tree topologies are required additional router nodes to establish multi-hop connections between coordinator and devices. The IEEE 802.15.4 standard is utilized in various industrial standards to accomplish monitoring and control applications. The ISA 100.11a, Wireless-HART, and the ZigBee are the most popular standards in this classification. The ZigBee is the most distinguished one rather than the other standards since it is widely approved in both industrial and commercial applications due to its capabilities on the network management. ZigBee systems employ digital radios with low power consumption depending on the IEEE 802.15.4 standard. The IEEE 802.11 standards utilize 2.4 or 5.8 GHz frequency band to standard the PHY and MAC layers of wide LANs (WLAN). The WLANs promote two different modes called ad hoc and infrastructure. The ad hoc permits stations to form a wireless LAN automatically where entire stations can communicate in peer-to-peer architectures with each other. In the second operation mode, the network contains at least one access point (AP) in its structure and each terminal is accessed through one or more than one access point to another.

There are various protocols such as Insteon, Z-Wave, SimpliciTI, EnOcean, Wavenis and Wireless M-BUS in applications apart from the above-mentioned standards [36]. The Insteon is an automation technology, which can be control electrical home appliances by using the PLC or wireless communication techniques. This protocol uses a dual mesh network topology at the 915 MHz frequency band [37]. The Z-Wave system has widely employed to control home appliances thanks to mesh network topology [38]. A protocol called SimpliciTI is developed by Texas

Table 16.4 Technical specifications and application areas of the wireless systems depend on the IEEE standards [36]

Protocols → Specifications ↓	ZigBee over IEEE 802.15.4	WirelessHART over IEEE 802.15.4	MIWi over IEEE 802.15.4	Isa100.11 over IEEE 802.15.4	Bluetooth (IEEE 802.15.1)	Wi-Fi IEEE 802.11 a/b/g/n/ac/i
Frequency	2.4 GHz/915 MHz (USA) 868 MHz(EU)					
RF channel numbers	16 (2.4 GHz)/10 (915 MHz) 1 (868 MHz)					
Network types	Peer-to-peer, mesh and star	Star, peer-to-peer and mesh	Star, peer-to-peer	Star, peer-to-peer and mesh	Star, peer-to-peer	Star, peer-to-peer
MAC scheme	CSMA/CA TDMA + CSMA/CA (star topology)	TDMA + CSMA/CA (beacon mode)	CSMA/CA (beaconless mode)	TDMA + CSMA/CA (beacon mode)	TDD	CSMA/CA + PCF
Mapping	BPSK (868-915 MHz) Q-QPSK (2.4 GHz)	O-QPSK (2.4 GHz)	FSK/OOK	O-QPSK (2.4 GHz)	GFSK/ DQPSK 8DPSK (optional)	BPSK, QPSK, COFDM, CCK, M-QAM
Nominal data rate	250 kbps (2.4 GHz) 40 kbps (915 MHz) 20 kbps (868 MHz)					
Encryption	AES128					
Data authentication	MIC-32; MIC-64; MIC-128 (shared key) ENC-MIC-32; ENC-MIC-64; ENC-MIC-128 (encrypted key)					
Data integrity	CRC16	CRC16	CRC32	CRC16	CRC32	CRC32

(continued)

Table 16.4 (continued)

Protocols → Specifications ↓	ZigBee over IEEE 802.15.4	WirelessHART over IEEE 802.15.4	MIWi over IEEE 802.15.4	Isa100.11 over IEEE 802.15.4	Bluetooth (IEEE 802.15.1)	Wi-Fi IEEE 802.11 a/b/g/n/ac/i
Autonomy (days)	100 to 1000+	Varies according to the battery features				
Coverage area (meters)	10–300	100	20–50	100–200	10	10–100
Application areas	Remote control and automation in buildings	Industrial and building control	Automatic metering, home and industrial applications	Industrial and control market	Wireless connectivity between devices	Wireless LAN, broadband internet access
Advantages	Low power consumption, different application profiles and topology flexibility	Security, reliability and compatibility with wired systems	Flexible, cost-effective	Low energy consumption, flexible and security	Speed and flexibility	

Table 16.5 Technical specifications and application areas of the wireless systems depend on the IEEE standards [36]

Protocols → Specifications ↓	SimpliciTI	Z-Wave	Insteon	EnOcean	Wavenis	WM-Bus
Frequency	2.4 GHz and Sub 1 GHz	2.4 GHz 908.4 MHz (USA) 868.4 MHz(EU)	915 MHz (USA)	315 MHz 902.875 MHz (USA) 868 MHz (EU)	433 MHz 868 MHz(EU) 915 MHz (USA) 2.4 GHz	169 MHz 433 MHz 868 MHz
RF channel numbers	Set by the application	2	34	1	1	12
Network types	Star and peer-to-peer	Mesh	Dual-mesh, peer to peer and mesh	Star, peer-to-peer and mesh	Star, peer-to-peer and mesh	Star, Peer-to-Peer
MAC scheme	LBT (listen-before-talk)	CSMA/CA	CSMA/CA	CSMA/CA	CSMA/TDMA and CSMA/CA	CSMA/CA
Mapping	MSK	FSK, GSK, narrowband	BPSK, FSK (in ISM Band)	ASK	GFSK	FSK, GFSK, MSK, OOK, ASK
Nominal data rate	Up to 250 kbps	9.6 kbps (868 MHz) 40 kbps (915 MHz)	38.4 kbps	120 kbps (868.3 MHz)	From 4.8 kbps to 100 kbps. Usually 19.2 kbps	2.4 kbps to 100 kbps
Encryption	Varies according to the MAC	AES128	No	No	3DES AES128	DES AES128
Data authentication	Varies according to the MAC	8-bit node I.D 32-bit home I.D	24 bit pre-assigned module I.D	8/32-bit	48-bit MAC addresses	-
Data integrity	Varies according to the MAC	Assigned by primary controller	CRC16	CRC8	BCH (32,21)	CRC16

(continued)

Table 16.5 (continued)

Protocols → Specifications ↓	SimpliciTI	Z-Wave	Insteon	EnOcean	Wavenis	WM-Bus
Autonomy (days)	Depends on battery specifications					
Coverage area (meters)	10	30	45 (outdoors)	No batteries (solar cells) 30	200 (indoors) 1000 (outdoor)	Up to 1000
Application areas	Distributed alarm and security devices, energy meters and home automation	Remote control lighting and automation, in residential and commercial buildings	Energy measurement, Energy savings, irrigation control, occupancy sensing, remote control heating, air conditioning	Building automation, smart homes, logistics, industry and transportation	Industrial automation, AMI, AMR, smart homes, lighting and access control, RFID applications	Smart meters (electricity, gas, water, and heat)
Advantages	Small code size and low software complexity	Controllers and slaves network, flexible network configuration	Reliability, low cost, scalability and flexibility	Ultra-low power, no batteries, easy to install and time is saved	Ultra-low-power energy consumption, multiple years battery life	Very cost effective

Instruments to provide simple and low-power RF network protocol. This protocol supports star and peer-to-peer network topology [39]. The EnOcean standard is firstly utilized automation systems in buildings, and then it is used in different areas such as industry, logistics and smart homes. The peer-to-peer, mesh and star network topologies can be established in this standard [40]. The Wavenis technology is introduced by Coronis systems as a wireless protocol to control and monitor several applications of home and building automation. The Wavenis technology supports the peer-to-peer, mesh and star network topologies. Although data rates of the Wavenis can be programmable up to 100 kbps, most applications exploits at 19.2 kbps [36]. The Wireless M-Bus (WM-Bus) standard has recently proposed for metering applications such as the SMs. The energy requirement of the WM-Bus is very low owing to used protocol and frequency bands. In addition, the WM-Bus can allow transmission over longer distances than that of the IEEE 802.15.4 standard [41]. Technical specifications and application areas of the wireless network protocols utilized in the smart homes are listed in Tables 16.4 and 16.5. All of these network protocols support power saving feature.

16.7 Conclusions

Smart home systems aim to integrate technology and services to provide a better living quality. These systems can provide several benefits to users such as connecting, controlling and monitoring home appliances. In addition, they can realize various functions according to predefined circumstances. The entire of these features can be achieved by the communication systems that are one of the most important components of the smart homes, smart buildings and nearly zero-energy buildings. Hence, the wired and wireless communication systems of the smart buildings and nearly zero-energy buildings are introduced in this chapter. When the wired communication systems are considered, the wired communication systems provide two crucial advantages such as reliability and insensitivity to interference. Recently, the PLC systems which are based on the idea of conveying any type of data by exploiting the power lines originally designed for electrical energy delivery have gained a great deal of attention in the field of communication, smart grid and home automation systems. The most important advantage provided by the PLC systems against the optic fiber and the DSL systems is clearly that they do not require a new communication medium owing to being power lines in living areas. Therefore, the strongest candidate among the wired communication systems in the smart homes is the PLC systems. On the other hand, the wireless technologies can be also considered to build wireless HAN in the smart homes. Hence, several wireless technologies that are IEEE or not IEEE based standards are discussed for the smart homes. The IEEE standards such as ISA 100.11a, Wireless-HART, ZigBee and the Wi-Fi are the most popular standards in this classification. The ZigBee technology is the most distinguished one rather than the other standards since it is widely approved in both industrial and commercial applications due to its capabilities on the network

management. Although the low-power and low data protocols provided by the MiWi, ZigBee or Wavenis are sufficient for energy management purposes in smart homes, the EnOcean and Insteon cannot ensure a satisfactory security feature. As a final remark, it is important to note that the wired and wireless communication technologies may be cooperated to establish an efficient, reliable and stable communication environment in the smart homes and smart buildings.

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