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Performance evaluation of multiple access techniques for broadband power line communication systems

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PERFORMANCE EVALUATION OF MULTIPLE ACCESS TECHNIQUES FOR BROADBAND POWER LINE COMMUNICATION SYSTEMS

By

Bertha Shao

Dissertation Submitted in Partial Fulfillment of the Requirements for the Degree of Master of Science in Telecommunications Engineering of the University of Dodoma

University of Dodoma

October, 2013

CERTIFICATION

The undersigned certify that they have read and hereby recommend for acceptance by the University of Dodoma dissertation entitled ***Performance Evaluation of Different Multiple Access Schemes for Broadband Poweline Communication Systems*** in fulfillment of the requirements for the degree of Master of Science in Telecommunication Engineering of the University of Dodoma.

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Prof. J. Anatory

(SUPERVISOR)

DATE……………………………….…

DECLARATION AND COPYRIGHT

I, **Bertha Shao** declare that this dissertation is my own original work and that it has not been presented and will not be presented to any other University for a similar or any other degree award.

Signature ………………………………………………………….

ACKNOWLEDGEMENT

I would like to give thanks to God the Almighty for everything that he has done for me during my studies. Life wasn’t so easy without you my God; you made every step possible for me.

I give my special appreciation to my supervisor, Prof. J. Anatory. Without his expertise, guidance, and advice, the goals of this dissertation would have been much more difficult to obtain. His efforts in providing me with constant feedback and encouragement are greatly appreciated.

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Special thanks go to my husband, my family and my friends, I can’t thank you enough but I pray always that God grants you all that you need and for success in all that you do.

DEDICATION

This work is dedicated to my lovely parents, my husband and my family for their support and wise words which have been of great importance in my academic life. They have always told me to see the challenges as stepping stones.

BE BLESSED ALWAYS.

ABSTRACT

Powerline communication (PLC) is a promising technique for information transmission using existing power lines. Broadband over power lines is the way of providing internet services to customers using high frequency signals integrated in the power wiring. The internet signals are modulated and coupled into the overhead power lines. The signals are decoupled at the consumer's premises. BPL can be a solution for people living in any rural area where there is electricity, since the cost of laying cables and building the necessary infrastructure to every house is too high, BPL can serve to cut down the costs by eliminating the need for laying new infrastructure.

A multiple access scheme of the MAC layer establishes a method of dividing the transmission resource into accessible sections. Multiple access techniques divide up to the total signaling resource into channels and then assign these channels to different users. The most common ways to divide up the transmission medium are along the time, frequency and/or code axes.

In this research FDMA and TDMA are the two multiple access schemes which are taken into consideration. Their performances under different channel conditions have been found. The channel conditions considered are low, medium and high disturbances. It was found that TDMA performs better than FDMA under all these channel conditions.

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LIST OF ABBREVIATIONS

ACK	Acknowledgement
BPL	Broadband Power Line
BPLC	Broadband Power Line Communication
BS	Base Station
CBR	Constant Bit Rate
CDMA	Code Division Multiple Access
CFS	Carrier Frequency Systems
CS	Circuit Switched
CSMA/CD	Carrier Sense Multiple Access/ Collision Detection
DCA	Dynamic Channel Assignment
DSL	Digital Subscriber Line
DS	Direct Sequencing
DSSS	Direct Sequence Spread Spectrum
FCA	Fixed Channel Assignment
FDD	Frequency Division Duplex
FDMA	Frequency Division Multiple Access
FCFS	First Come First Served
FDD	Frequency Division Duplex
FEC	Forward Error Control
FH	Frequency Hopping
FHSS	Frequency Hopping Spread Spectrum
IP	Internet Protocol
ISI	Inter-Symbol Interference
LAN	Local Area Network
MAC	Multiple Access Control
NAWGN	Non-Additive White Gaussian Noise
OFDM	Orthogonal Frequency Division Multiplexing
OFDMA	Orthogonal Frequency Division Multiple Access
PLC	Power line Communications
PSD	Power Spectral Density
QoS	Quality of Services
RCS	Ripple Carrier Signaling

RP	Repeater
SS	Subscriber Station
TCP	Transport Control Protocol
VBR	Variable Bit Rate
WWW	World Wide Web

LIST OF SYMBOLS

D	Delay
G	Offered traffic
n	Number of packets
N	Number of subscriber stations
R	Data rate
S	Throughput

CHAPTER ONE

INTRODUCTION

1.1 General introduction

Broadband over power lines is the way of providing internet services to customers using high frequency signals integrated in the power wiring. The internet signals are modulated and coupled into the overhead power lines. The signals are decoupled at the consumer's premises (Ngeze, 2008). Despite of the fact that broadband over power lines technology has been increased in the last few years, there is still the large area of the world that doesn't have access to high speed internet, especially the developing countries like Tanzania.

Broadband over power lines is a technology that provides high-speed internet through the use of an electric power line to homes or offices. It can transmit data between 500kbps and up to a theoretical speed of 3Mbps over power lines to homes and offices which are almost equivalent to most Digital Subscriber Line (DSL) and cable modem transmission rates. To develop BPL technology, every home and office must be connected to the power grid and contains electrical wiring (Hrasnica *et. al*., 2004).

BPL can be a solution for people living in any rural area where there is electricity, since the cost of laying cables and building the necessary infrastructure to every house is too high. BPL can serve to cut down the costs by eliminating the need for laying new infrastructure. By modifying the existing power grids with additional equipments, the BPL developers could join hands with power companies and internet providers to bring broadband services to everyone with access to electricity and hence increased understanding of the existing world.

1.2 Problem statement

Originally, powerline was designed for electrical transmission. Advancement in technology allows powerline to transmit data using sophisticated signal processing techniques. At the MAC layer the power-line network operates as a shared medium. Therefore only one user can transmit at a time. At the same time shared media networks are not suitable as large networks as there are limitations to the number of nodes you can set up. This is because as the number of computers increase in the network the data transfer rate goes down accordingly and noticeably.

A multiple access scheme of the MAC layer establishes a method of dividing the transmission resource into accessible sections. In the case of multiple subscribers using a shared transmission medium, telecommunications signals (information patterns) from individual users have to be transmitted within separated accessible sections, provided by a multiple access scheme, ensuring error-free communications. For this purpose, the signals from different subscribers, when they are transmitted over a shared medium, have to be orthogonal to each other.

Different researchers have devoted their efforts to find appropriate MAC protocol for powerline networks; these include ALOHA, CSMA/CD and others. However, the future trends of data are mostly based on multimedia applications which need a dedicated channel. This demands a new multiple access technique.

To overcome current and future demands multiple access protocols for BPLC must take into account the evolution of applications as more services are introduced plus the increase of number of users. A suitable multiple access protocol that oversees these and other key factors that affect performance powerline must be identified.

1.3 Objectives

1.3.1 Main objective

The main objective of this dissertation is to determine a suitable multiple access technique for BPLC.

1.3.2 Specific objectives

1. To determine the modeling techniques of PLC MAC layer.

2. To compare the performance of multiple access schemes under different channel conditions of PLC.

1.3.3 Research questions

1. How the MAC can be modeled?

2. How performance of multiple access schemes under different channel conditions can be compared?

1.4 Significance of the study

This study will provide the efficient MAC protocol that meets current and future applications of BPLC and that takes into account the growth of number of users in BPLC. The study will also increase the knowledge and skills to interested parties like researchers. Also BPLC equipment manufacturers and standard committees will benefit in time of which MAC protocol should be included or excluded in their equipment standards.

CHAPTER TWO

LITERATURE REVIEW

2.1 Power Line Communications Background

The application of electrical supply networks in telecommunications has been known since the beginning of the twentieth century. The first Carrier Frequency Systems (CFS) had been operated in high-voltage electrical networks that were able to span distances over 500 km using 10-W signal transmission power. Such systems have been used for internal communications of electrical utilities and realization of remote measuring and control tasks. Also, the communications over medium and low voltage electrical networks has been realized. Ripple Carrier Signaling (RCS) systems have been applied to medium and low voltage networks for the realization of load management in electrical supply systems (Hrasnica *et. al.,* 2004).

Powerline Communications is the usage of electrical power supply networks for communication purposes. In this case, electrical distribution grids are additionally used as a transmission medium for the transfer of various telecommunications services. The main idea behind PLC is the reduction of cost and expenditure in the realization of new telecommunications networks.

High or middle voltage power supply networks could be used to bridge a longer distance to avoid building an extra communications network. Low voltage supply networks are available worldwide in a very large number of households and can be used for the realization of PLC access networks to overcome the so called telecommunications “last mile” (Hrasnica *et. al*., 2004). Powerline communications can also be applied within buildings or houses, where an internal electrical installation is used for the realization of in-home PLC networks.

Internal electrical networks have been mostly used for realization of various automation services. Application of in-home PLC systems makes possible the management of numerous electrical devices within a building or a private house from a central control position without the installation of an extra communications network. Typical PLC-based building automation systems are used for security observance, supervision of heating devices, light control, and so on (Hrasnica *et. al*., 2004).

For multi-user communication links, resources of the channel have to be shared among a large number of users. Apart from modulation and coding schemes, in multiuser communication the way in which multiple users access a common channel is crucial for the performance. In principle the multiple accesses is arranged by a multiple access protocol. Beside channel properties the choice of a suitable access method is determined by requirements on data transmission in terms of delay time, data amount and duty cycle. Furthermore in PLC we have to distinguish between downlink and uplink. For downlink (basestation to the user) a fixed multiple access method is more suitable, due to the structure of the network (Hrasnica *et. al*., 2004). A central master in the basestation controls channel access. As attenuation of the channel depends on length of the link, an FDMA-scheme is suggested. Users at a large distance from the basestation may then use lower frequencies for transmission whereas closer users encounter a sufficient signal to noise ratio for transmission even in upper frequency bands. Users at equal distance from the basestation therefore are normally assigned to the same frequency slot, using TDMA within their common frequency slot as multiple access method for down-link (Langfeld *et. al.*, 2000).

2.2 Structure of powerline communication

The electrical supply systems consist of three network levels that can be used as a transmission medium for the realization of PLC networks (Hrasnica *et. al*., 2004). Figure 2.1 below shows the structure:

• High-voltage (110–380 kV) networks connect the power stations with large supply regions or big customers. They usually span very long distances, allowing power exchange within a continent. High-voltage networks are usually realized with overhead supply cables.

• Medium-voltage (MV) (10–30 kV) networks supply larger areas, cities and big industrial or commercial customers. Spanned distances are significantly shorter than in the high-voltage networks. The medium-voltage networks are realized as both overhead and underground networks.

• Low-voltage (230/400 V, in the USA 110 V) networks supply the end users either as individual customers or as single users of a bigger customer. Their length is usually up to a few hundred meters. In urban areas, low-voltage networks are realized with underground cables, whereas in rural areas they exist usually as overhead networks.

• In-home PLC (indoor) systems use internal electrical infrastructure as transmission medium. It makes possible the realization of PLC local networks within houses, which connect some typical devices existing in private homes; telephones, computers, printers, video devices, and so on. In the same way, small offices can be provided with PLC LAN systems. In both cases, the laying of new communications cables at high cost is avoided.

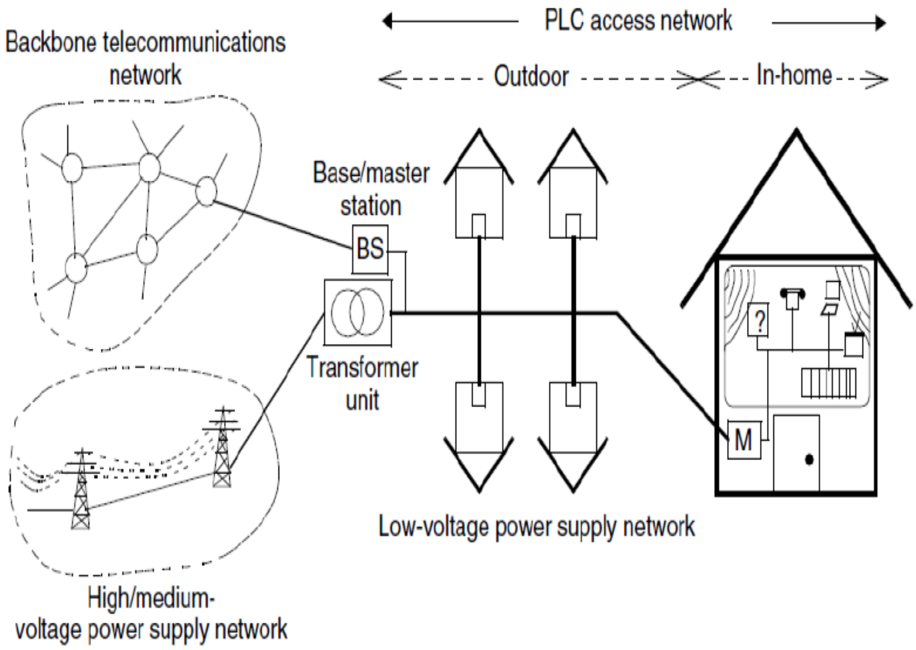

Figure 2.1: Structure of PLC (Source: Hrasnica *et. al*., 2000)

In-home electrical installations belong to the low-voltage network level. However, internal installations are usually owned by the users. They are connected to the supply network over a meter unit (M). On the other hand, the rest of the low-voltage network (outdoor) belongs to the electrical supply utilities. Low-voltage supply networks directly connect the end customers in a very large number of households worldwide. Therefore, the application of PLC technology in low-voltage networks seems to have a perspective regarding the number of connected customers. On the other hand, low-voltage networks cover the last few hundreds of meters between the customers and the transformer unit and offer an alternative solution using PLC technology for the realization of the so-called "last mile" in the telecommunications access area (Hrasnica *et. al*., 2000).

Basically, the structure of an in-home PLC network is not much different from the PLC access systems using low-voltage supply networks. There can also a base station that controls an in-home PLC network, and probably connects it to the outdoor area. The base station can be placed with the meter unit, or in any other suitable place in the in-home PLC network. All devices of an in-home PLC network are connected via PLC modems, such as the subscribers of a PLC access network. The modems are connected directly to the wall power supply sockets (outlets), which are available in the whole house/flat. Thus, different communications devices can be connected to the in-home PLC network wherever wall sockets are available (Hrasnica *et. al*., 2004).

2.3 PLC Services

The PLC systems have to offer telecommunications services with satisfied quality of services (QoS) to be able to compete against other access technologies. PLC system has to implement the MAC protocol which has to provide features for realization of different teleservices such as (Halid *et. al*., 2000):

- Connection oriented services, like telephony and other CBR (Constant Bit Rate) services
- Connectionless services without QoS guarantees (e.g. Internet)
- Specific PLC services
- Data transmission with QoS guarantees (like VBR – Variable Bit Rate – services)

PLC networks must support the classical telephone service, because of its importance and its big penetration in the communications world. Another important service is data transmission, which allows internet usage. The powerline MAC layer has to be able to deal with both mentioned services to ensure an initial position of the PLC systems against other technologies. Also, a possibility for transmission of more sophisticated services, with higher QoS requirements (e.g. VBR, CBR with higher data rates) as well as the features for specific PLC services (home automation, energy management, security) should be included into the PLC MAC layer.

2.4 Multiple Access Schemes

A multiple access scheme establishes a method of dividing the transmission resources into accessible sections, which are used by multiple subscribers using various telecommunications services. A multiple access scheme is applied to a transmission medium (e.g. wireline or wireless channel) within a particular frequency spectrum, which can be used for information transfer equation (Hrasnica *et. al.,* 2004).

Multiple access techniques divide up to the total signaling resource into channels and then assign these channels to different users. The most common ways to divide up the transmission medium are along the time, frequency and/or code axes (Goldsmith, 2005).

For multiuser communication links, resources of the channel have to be shared among a large number of users. In principle the multiple access is arranged multiple access protocol. Beside channel properties the choice of suitable access method is determined by requirements on data transmission in delay time, data amount and duty cycle (Langfeld *et. al*., 2000**).**

2.4.1 Classification of multiple access protocol

Multiple access protocols can be divided into fixed access and random protocols as shown in the figure 2.2. Fixed access (conflict-free) protocols ensure that whenever a transmission is made on error-free channels, it will not be interfered by another transmission, and thus is successful. Conflict-free transmission can be achieved by allocating the channel to the users either statically or dynamically. Channel resources can be divided in terms of time, frequency or combination of time and frequency (Chan, 2000).

A system employing random access (or contention) protocols allows users to access the channel at any time; this results into collisions in which conflicts need to be resolved. As show in the figure, the random access protocols are divided into repeated random protocols and random protocols with reservation. In random protocols with reservation, a user's initial transmission uses a random access method to gain access to the channel. Following transmissions are then scheduled until there is nothing more to send (Chan, 2000).

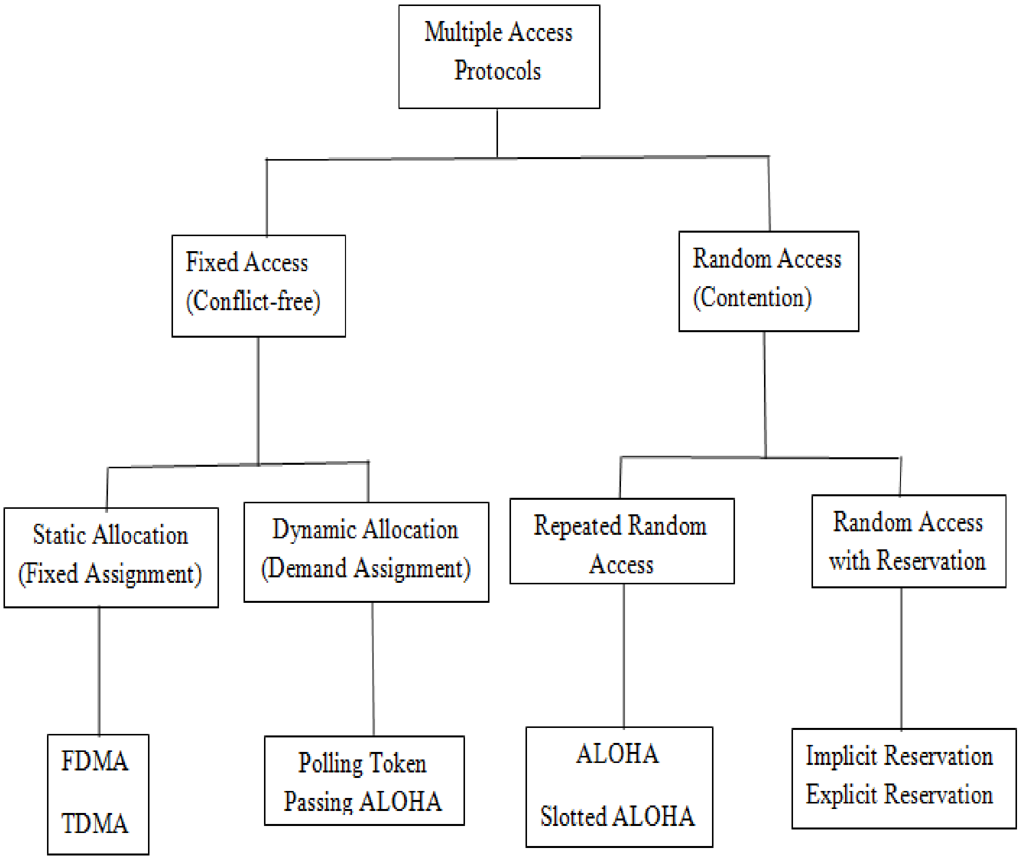

Figure 2.2: Classification of Multiple Access Schemes

2.4.2 Fixed access protocols

In the fixed access protocols, the available channel capacity is divided among the users such that each user is allocated a fixed part of the capacity, independent of its activity (Harada *et. al.*, 2002). An important advantage of conflict-free access protocols is the ability to ensure fairness among users and the ability to control the packet delay- a feature that may be essential in real-time applications.

2.4.2.1 Frequency Division Multiple Access (FDMA)

In FDMA the system signaling dimensions are divided along the frequency axis into non-overlapping channels, and each user is assigned a different frequency channel. The channels often have guard bands between them to compensate for imperfect filters, adjacent channel interference, and spectral spreading due to Doppler. If the channels are sufficiently narrowband then even if the total system bandwidth is large, the individual channels will not experience frequency-selective fading. Transmission is continuous over time, which can complicate overhead functions such as channel estimation since these functions must be performed simultaneously and in the same bandwidth as data transmission (Goldsmith, 2005).

FDMA scheme can be implemented in different transmission systems, such as spread spectrum and OFDM-based transmission systems, which are considered as suitable for realization of broadband PLC systems (Hrasnica *et. al.*, 2004). OFDM (Orthogonal Frequency Division Multiplexing) use orthogonal subcarriers for sending several data symbols in parallel resulting in better spectral efficiencies and simple equalization methods at the receiver **(**Srikanth *et. al.*, 2010**).**

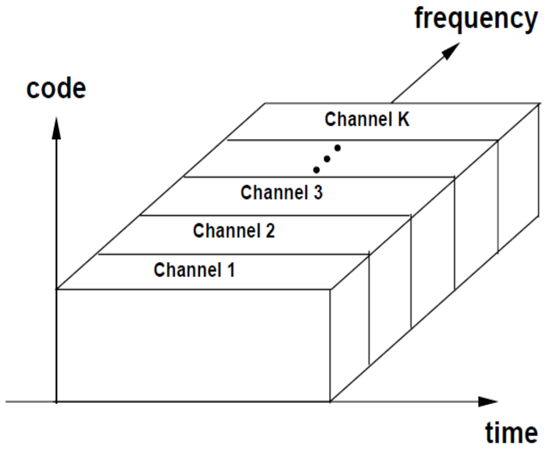

Figure 2.3: FDMA

2.4.2.1.1 OFDM Access (OFDMA)

In OFDMA both time and/or frequency resources are used to separate the multiple user signals. Groups of OFDM symbols and/or groups of subcarriers are the units used to separate the transmission to/from multiple users **(**Srikanth *et. al.,* 2010). According to the OFDMA scheme, the subcarriers with relatively low data rates are grouped to build up the transmission channels with higher data rates providing a similar FDMA system. However, the protection frequency bands, which are necessary in FDMA to separate different transmission channels, are avoided in an OFDMA system thanks to the provided orthogonality between the subcarriers. The subcarriers of a transmission channel can be chosen to be adjacent to each other, or to be spread out in the available frequency spectrum (Hrasnica *et. al.,* 2004).

2.4.2.1.2 OFDMA/TDMA

In this case, the transmission channels, which are divided in a frequency range, are also divided into time slots with a fixed or variable duration. Accordingly, each time slot carries a data segment with a fixed or variable size. The data segments present the smallest accessible portions of the network resources provided by the

OFDMA/TDMA scheme, which are managed by a MAC protocol. Thus, in the case of OFDMA/TDMA, the MAC protocol controls access to both transmission channels and time slots (Hrasnica *et. al.*, 2004).

Each transmission channel consists of a number of subcarriers, which can be grouped in different ways, as is provided by the OFDMA scheme. Accordingly, a transmission channel can include a variable number of subcarriers or a fixed number of subcarriers with variable data rates (bit loading), causing variable data rates of the transmission channel as well. On the other hand, a time slot carrying a data segment consists of a number of OFDM symbols with a certain duration and payload capacity, as is described above for an OFDM/TDMA system. In any case, the number of the OFDM symbols per time slot and per channel, which corresponds to a data segment, has to be an integer (Hrasnica *et. al.*, 2004) as shown in fig. 2.4.

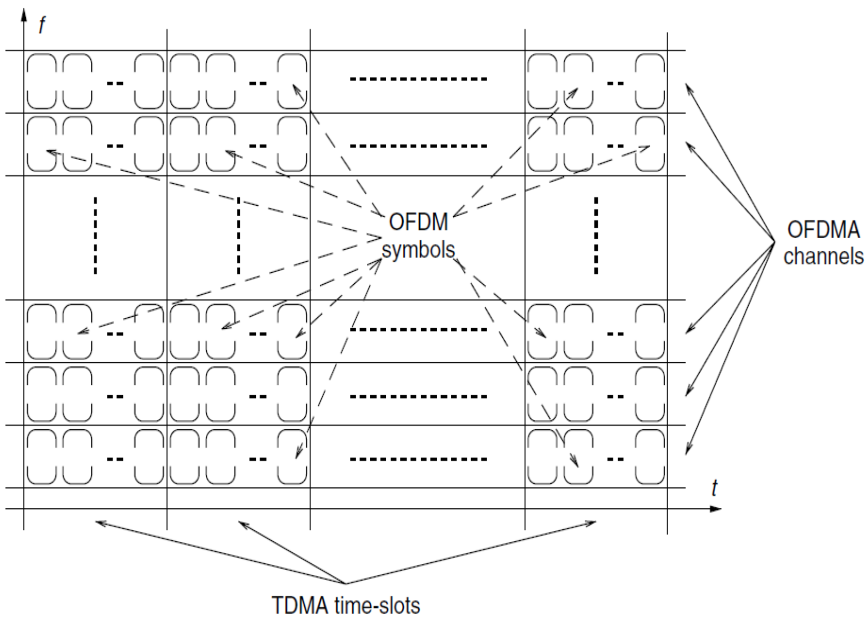

Figure 2.4: OFDMA/TDMA (Source: Hrasnica, 2000)

2.4.2.2 Time Division Multiple Access (TDMA)

It allows several users to share the same frequency channel by dividing the signal into different time slots. The users transmit in rapid succession, one after the other, each at his time slot. This allows multiple stations to share the same transmission medium (e.g. radio frequency channel) while using only a part of its channel capacity. The operation of TDMA requires an out link control to all the remote sites which contains some control information. This out link carrier also had a frame structure that provides accurate timing information for all the remote sites.

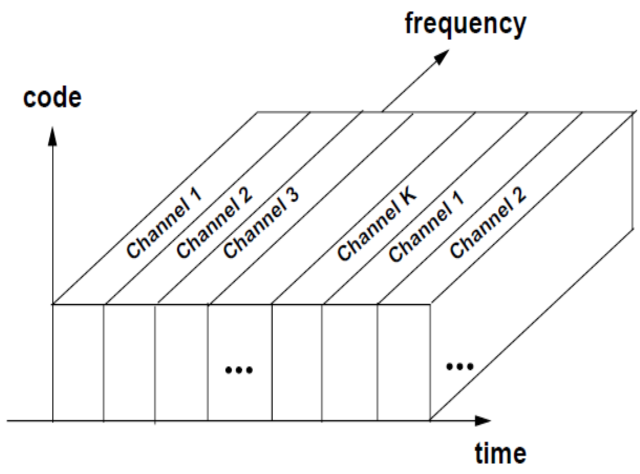

Figure 2.5: TDMA

2.4.2.2.1 OFDM/TDMA

In this case, the network resources are divided into time slots, each of them carrying an integer number of OFDM symbols. The length of the time slots can be fixed or variable, but the number of OFDM symbols within a time slot has to be an integer.

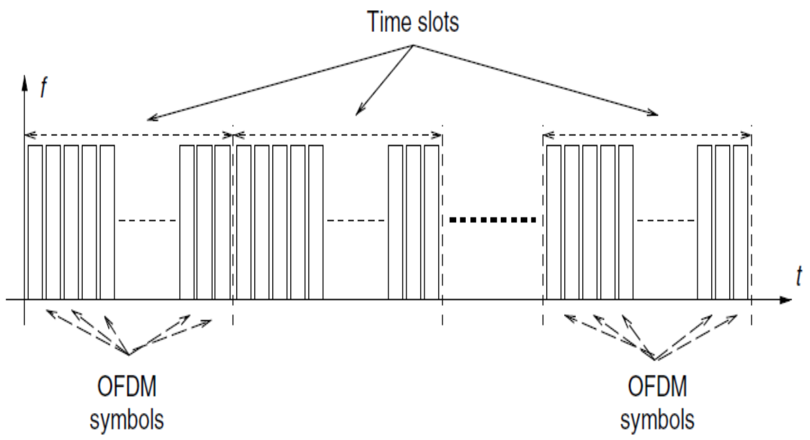

Figure 2.6: OFDMA/TDMA (Source; Hrasnica *et. al.*, 2004)

2.4.2.3 Code Division Multiple Access (CDMA)

In CDMA, the entire available frequency band and time are considered a unit where all clients send at the same time. The receivers receive the superposition of all signals and filter the signals addressed to them by a correlation of the received signal with a code sequence. In order to successfully calculate the correlation on the receive signal, all signals must have an amplitude within the simultaneously available dynamic range of the receiver (Bumiller, 2001).

CDMA employs spread-spectrum technology and a special coding scheme (where each transmitter is assigned a code) to allow multiple users to be multiplexed over the same physical channel. By contrast, TDMA divides access by time, while FDMA divides it by frequency. CDMA is a form of spread spectrum signaling, since the modulated coded signal has a much higher data bandwidth than the data being communicated (Hrasnica *et. al.*, 2004).

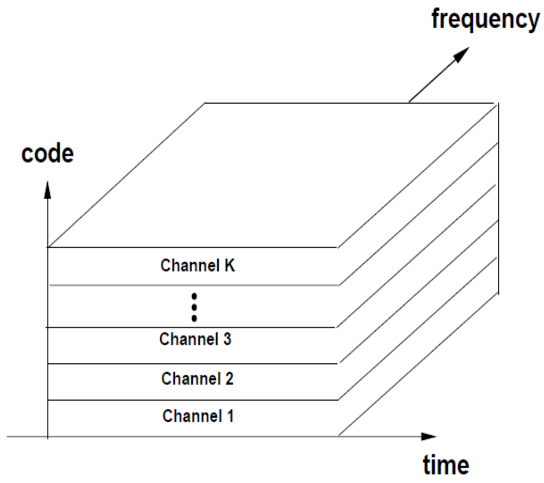

Figure 2.7: CDMA

CDMA can be realized by the application of several coding methods, which are (Hrasnica *et. al.*, 2004):

- DS-CDMA – Direct Sequencing CDMA – based on Direct Sequence Spread Spectrum (DSSS) method, where each user's data signals are multiplied by a specific binary sequence. In this coding system, all subscribers of a network use the entire available frequency spectrum of a transmission medium. To be able to distinguish between different subscribers, data signals from different network users are multiplied by different code sequences, which are chosen to be unique for every individual user or connection. At the receiver side, the arriving signal is again multiplied by the uniquely specified code sequence. The result of the multiplication is the originally sent data signal, which is extracted between all other data signals, multiplied by different code sequences. Figure 2.8 shows how DS-CDMA works.

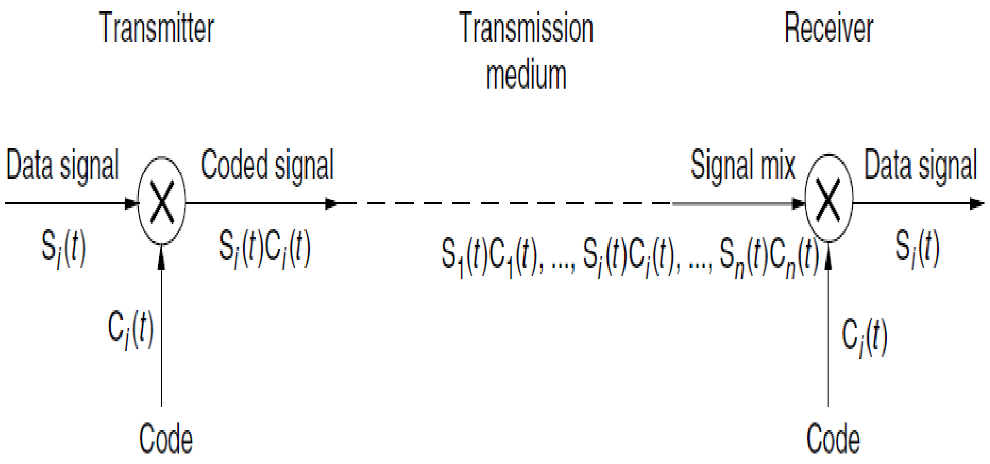

Figure 2.8: DS-CDMA (Source: Hrasnica *et. al.*, 2004)

From the figure above, data signal S*i (t)*, generated by user *i*, is multiplied by its corresponding code sequence C*i (i)* building a coded signal S*i (t)*C*i (t)*, which is transmitted over a medium. A receiving user listens to the transmission medium and can receive coded signals generated by all network users, so-called "signal mix" S1*(t)*C1*(t)* to S*n(t)*C*n(t)*, originated by application of their own codes. However, to receive and decode the original data signal S*i (t)*, it is necessary to multiply the signal mix by the unique code sequence C*i (t)*, which is only known or currently applied by the receiving user (Hrasnica *et. al.*, 2004).

- FH-CDMA – Frequency Hopping CDMA – based on Frequency Hopping Spread Spectrum (FHSS) method, where the transmission is spread over different frequency bands, which are used sequentially.

  FH-CDMA systems use only a small part of the frequency band, but the location of this part differs in time. During a time interval, the carrier frequency remains constant, but in every time interval, it hops to another frequency. The hopping pattern is determined by a code signal, similar as in a DS-CDMA system. Thus, the transmission channels in an FH-CDMA system are defined by the specific code as well. So, during a data transmission, a subscriber uses different frequency bands. The change of the frequency bands in the time is specified by the code sequence, allocated to the subscriber. In a special case, if the codes allocated for the individual users always point to the same frequency band, the same users always transmit over the same frequency bands, which lead to a classical FDMA system. Figure 2.9 shows the time/frequency diagram for FH-CDMA (Hrasnica *et. al.*, 2004).

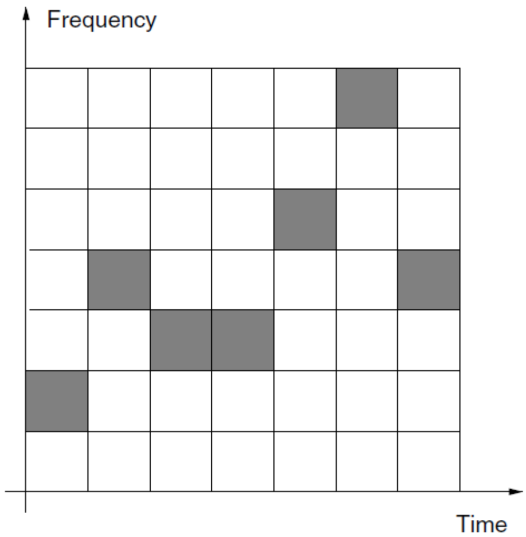

Figure 2.9: FH-CDMA (Source: Hrasnica *et. al.*, 2004)

2.4.3 Random access protocol

In random access or contention methods, no station permits or does not permit, another station to send. At each instance, a station that has data to send uses a procedure defined by the protocol to make a decision on whether or not to send (Forouzan, 2007). In other words, each station can transmit when it desires to on the condition that it follows the predefined procedure, including testing of the state of the medium. With random access protocols there is no scheduling of transmissions. This means that a user getting ready to transmit does not have exact knowledge of when it can transmit without interfering with the transmissions of other users (Harada *et. al.,* 2002).

Contention (random access) schemes differ from conflict-free (fixed access) schemes in principle since a transmission is not guaranteed to be successful from user. To guarantee successful transmission of messages, the protocol must provide the way to resolve conflicts once they occur. Another difference is how to handle the idle users in conflict-free scheme the idle users consume a portion of the channel resources, this wasteful of resource becomes impractical when there are a large number of users in the system. In contention schemes the idle users do not transmit and do not consume any portion of channel resources (Chan, 2000).

Two features give this method its name: (1) there is no scheduled time for a user to transmit. Transmission is random among all users, hence the name random access. (2) no rules specify which user should send next. Users compete with one another to access the channel medium. That is why these methods are also called contention methods (Fourozan, 2007).

2.4.3.1 Pure ALOHA

Users are allowed to send packets whenever they have anything to transmit, regardless of what other users are doing. That is each user sends a packet whenever it has a packet to send. Since there is only one channel to share, there is the possibility of collisions between packets from different users.

There are two ways in which the sender can learn if the packet has been successfully received at its destination: (1) if all users are able to observe all transmissions, the sender can determine whether its packet has collided with any other; (2) an acknowledgment packet can be sent from destination. An unsuccessful packet has to be retransmitted. In order to avoid collision, the senders must wait a random amount of time before retransmitting (Chan, 2000**).**

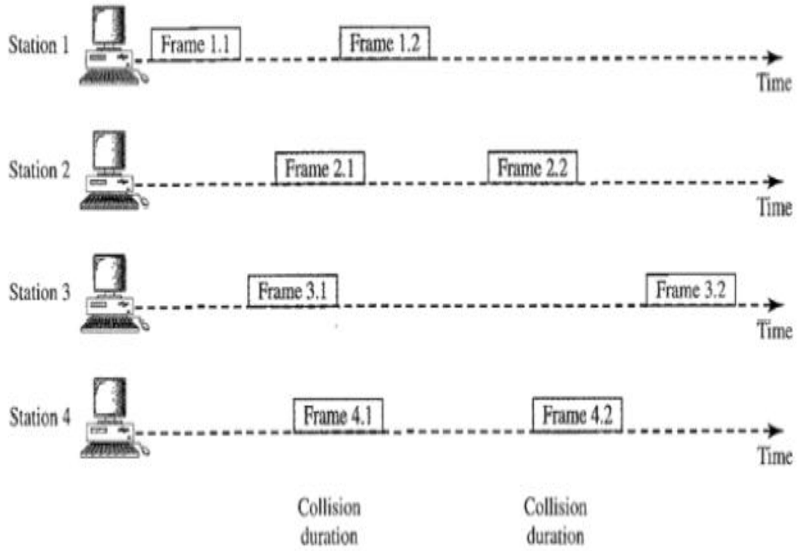

Figure 2.10: Pure ALOHA (Source: Forouzan, 2007)

2.4.3.2 Slotted ALOHA

In this case the channel is divided into time slots and all the packets are sent within the slot. This time synchronization is to improve the poor performance of pure ALOHA by reducing packet collisions. Because the sender is allowed to send only at the beginning of the synchronized time slot, if a sender misses this moment, it must wait until the beginning of the next time slot. Collision occurs when two senders try to send at the beginning of the same time slot (Fourazan, 2007).

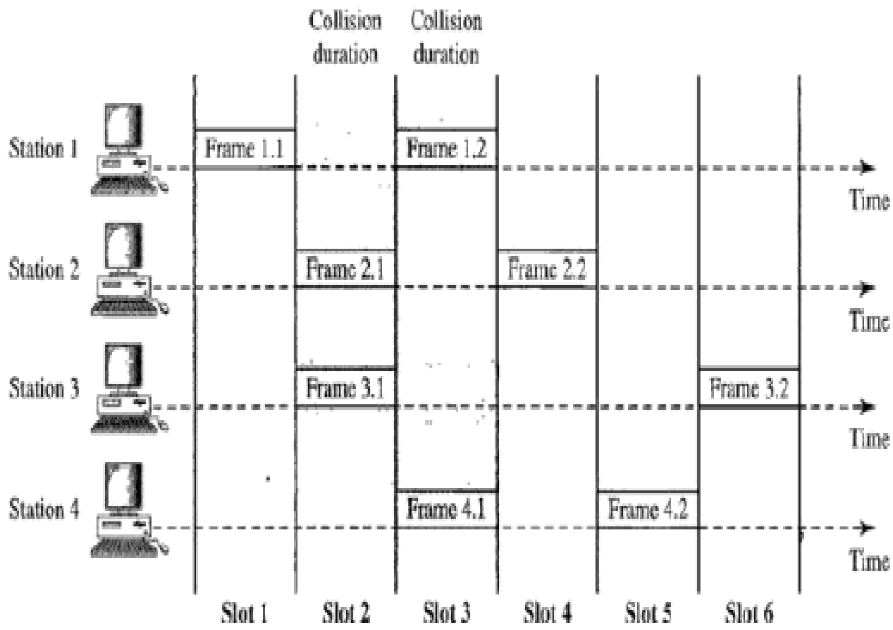

Figure 2.11: Slotted ALOHA (Source: Forouzan, 2007)

The contention access protocols avoid collisions between the transmissions of different network users. These protocols cannot ensure any guarantees of QoS for time-critical services and also full network utilization cannot be reached. Because of the fact that the powerline systems work with a limited data rates and that they should provide various telecommunication services, we conclude that the contention protocols are not suitable for PLC networks.

The multiple access schemes analyzed in this project are FDMA and TDMA. Their performances in powerline communication will be analyzed and the one which performs better will be revealed.

2.5 PLC Network Structure

The PLC access network is connected to the backbone communication networks through transformer stations or any other station in the network. There are also several network sections from a transformer unit to the users where the network sections have also different topologies (Hrasnica et al, 2000). The PLC backbone network is a conventional telecommunication system. The transmission signal from the backbone must be converted in a form which makes it possible for transmission over a low-voltage power supply network. The conversion takes place in a main/base station of the PLC system (usually placed in the transformer station) (Hrasnica *et. al.*, 2000).

On the user side, the PLC users/subscribers are connected to the PLC access network through PLC modem, which is placed in the electric power meter unit (M, Figure 2.12). Within a house, the transmission can be realized via a separated communication network or via an internal electric installation (In-Door PLC solution).

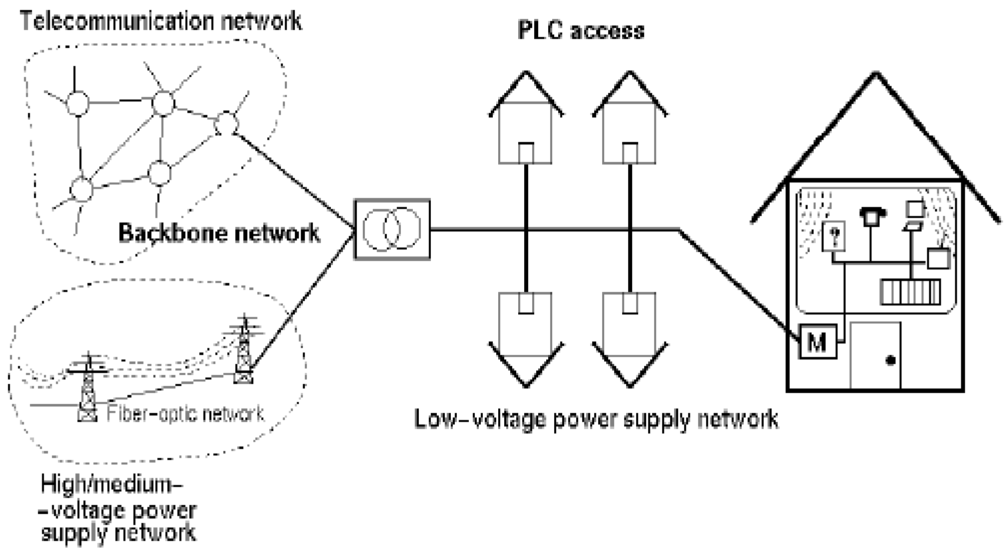

Figure 2.12: PLC Access Network (Source: Hrasnica *et. al.*, 2004)

In this investigation the PLC network topology and its effect to the MAC layer are considered. The several factors on which the topology of low-voltage power supply network depends are:

- Location of the PLC network: urban or rural residential area, industrial area, business area
- User/subscriber density: number of users in a PLC network (small-middle-large), user concentration (single houses-small blocks-towers)
- Network length: short-middle-long
- Network design: number of network sub sections

The communication between the user and PLC network and a wide area network (WAN) is carried out over a base station, normally placed in the transformer unit.

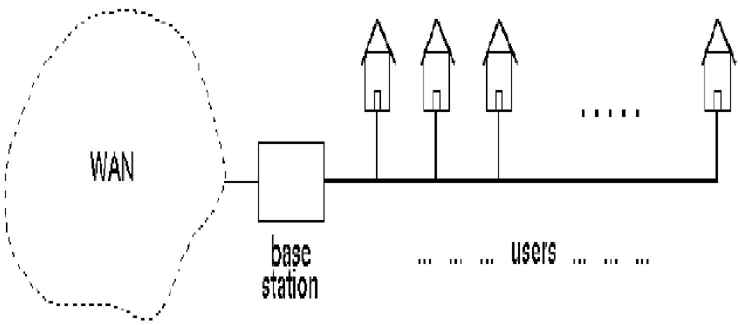

Figure 2.14: PLC network model (Source: Hrasnica, 2000)

Also the internal communication between users of a PLC network is done over a base station. Within a PLC network two transmission directions can be recognized:

- Downlink/downstream – for transmission from the base station to the network users
- Uplink/upstream – providing transmission from each user to the base station.

2.6 Channel Modeling

2.6.1 Introduction

The powerline communication (PLC) channel is influenced by various disturbances. Reflections of the transmitted, signal on impedance discontinuities result in signal echoes on the powerline channel. In this case the receiver gets the transmitted and the reflected signal. Therefore the powerline channel could be considered as similar to a multipath environment**.**

The transmission performance of the powerline channel is also influenced by the electrical load. Additional electrical appliances on the network could change the amplitude and the phase characteristic of the network impedance. The time constant for changing the network impedance is usually greater than the time for transmitting a symbol. So the changes of the network impedance could be eliminated e.g. by periodical test sequences. The transmitter and the receiver use the test sequences to adjust their transmission parameters to the actual channel impedance.

2.6.2 Noise Description

The noise on the PLC channel is generated primarily by electrical loads and by radiated disturbances from the environment. In the following, a connected electrical appliance, which injects noise into the PLC channel, is referred to as a single disturbance. The various noise sources for the powerline channel could be classified into sources which produce (Hrasnica *et. al.*, 2000): (1) synchronous disturbances with the main voltage frequency, (2) smooth spectrum noise, (3) single-event impulse noise and (4) non-synchronous periodic noise**.** The total noise level on the PLC channel is represented by the superposition of impulse disturbances and background noise. Present PLC transmission systems work in discreet frequency bands between 1 MHz and 30 MHz.

The powerline channel presents a non-additive white Gaussian Noise (NAWGN) environment because it was not designed for information transmission. The noise is considered as superpostion of five noise types as shown in fig. 2.15 below (Hrasnica *et. al.,* 2000).

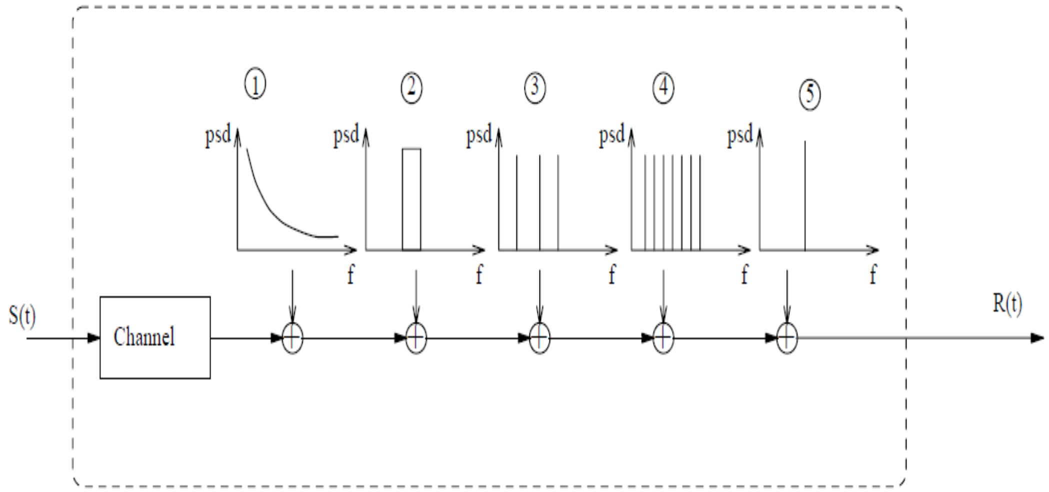

Figure 2.15: The additive noise in the Powerline Environment (Source: Hrasnica et. *al.,* 2000)

- Type 1, colored background: is the summation of numerous noise sources with low power, whose variation is slow over long time periods. Its power spectral density (psd) decreases as frequency increases.
- Type 2, narrowband noise: is a noise confined to a narrow portion of the frequency band. The main cause of this noise is the ingress of broadcast stations in the medium and short wave broadcast bands. The level varies with daytime, high in the evening because of the atmosphere reflection and much low by daylight.
- Type 3, periodic impulsive noise, asynchronous to the means frequency: this

type is caused by switching power supplies. These pulses have in most cases a repetition rate between 50 kHz to 200 kHz.

- Type 4, periodic impulsive noise, synchronous to the means frequency: is caused by power supplies operating synchronously with the main cycles, with a repetition rate of 50 Hz or 100 Hz. They are of short duration and have a psd decreasing with frequency.
- Type 5, asynchronous impulsive noise: with duration of microsecond up to milliseconds, are generated by the switching transients' events in the network. This type is regarded as the worst noise in the powerline environment, due to its magnitude which can easily reach several dB over the other types.

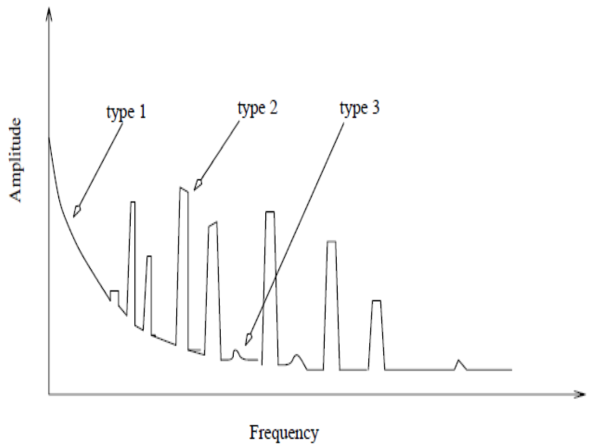

Figure 2.16: General Background Noise Spectrum (Source: Hrasnica *et. al.*, 2000)

Noise type 1, 2, and 3 can be lumped together as background noise (figure 2.16). While the background noise is stationary over seconds, minutes or hours, the short time variance in the powerline environment is introduced by noise types 4 and 5, which have duration in terms of microseconds and milliseconds (Hrasnica *et. al.*, 2000).

In impulsive noise (types 4 and 5), the channel can be modeled by a Markovian chain with two states, T_on and T_off *(figure 2.16*). T_off represents the duration of an impulse, during which the channel is considered as disturbed and there is no information transmission. T_on represents tthat there are no impulses and channel is available for information transmission. These states can be represented by two random variables, which are distributed exponentially (Hrasnica *et. al*., 2000). This channel is called PLC channel availability model

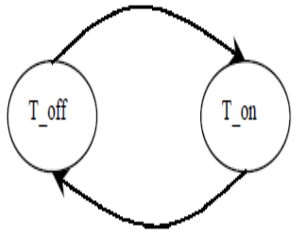

Figure 2.17: PLC Channel Availability Model (Source; Hrasnica *et. al.,* 2000)

2.7 Traffic modeling

For the investigation of the MAC layer, it is necessary to model the data traffic and to represent the behavior of its input data.

2.7.1 Modeling Telephony Traffic

The signaling procedure is carried out for each transmitted packet, in the case of data connections, in accordance with the per-packet reservation principle, and per connection for the telephony, according to the per-connection reservation principle. The arrivals of the voice connections are in a range of minutes, whereas the data packets, for example, caused by an Internet connection, are generated in a range of seconds. Thus, it can be seen that the arrival rate of the voice connections is significantly lower when compared with arrivals of IP packets. Accordingly, the arrival rate of the transmission requests for data transmissions is much higher than in the case of telephony (Hrasnica *et. al.,* 2004).

2.7.2 Simple Internet Traffic Models

Data traffic is characterized by two random variables; mean packet size and interarrival time of packets. The arrival of the data packets is very often described as a Poisson process and negative exponential distributions are usually used for modeling the interarrival time. The packet size is modeled as a geometrically distributed random variable (Hrasnica *et. al.,* 2004).

2.8 Performance Indicators

Multiple access communication involves the sharing of communication channel between multiple users. Multiple access schemes allocate the channel to each user that provides desirable performance characteristics.

2.8.1 Access terminal

The performance of each user terminal is the same and also each terminal has a buffer. The buffers are used to store generated transmission packets generated by each user terminal. The stored packets are transmitted in accordance with the order by which they came into buffer, that is, the buffer circuit is a first-in and first-out (FIFO) buffer. The buffer circuit can be categorized into two types: a buffer with finite memory and a buffer with infinite memory (Harada *et. al.,* 2002).

When the buffer with finite memory is used and the memory is full, the generated packets from user terminal are abandoned. This is called call blocking. If the number of access terminal is unlimited, then the model is called an infinite call-source model (Harada *et. al.,* 2002).

2.8.2 Packet generation

The packets are generated randomly and independently in each access terminal. This type of generation is called the Poisson distribution. The Poisson distribution has the following characteristics (Harada *et. al.,* 2002). :

- Independence: the generation of the packet does not depend on the previous generation.
- Constancy: in each time slot of the simulation, the probability of the packet does not change.

Rareness: in every small period, the probability in which more than two packets generated can be disregarded. Moreover, if the number of packets generated follows a Poisson distribution, the period until a packet is generated follows an exponential distribution (Harada *et. al.,* 2002)..

2.8.3 Offered traffic

Offered traffic is the total quantity of the packet that include newly generated packets and retransmission packets at the access point in a time interval. The normalized offered traffic by a transmission data rate is shown as *G* (Harada *et. al.,* 2002).

If the transmission data rate is *R* (bps) and *T* (bit) is requested to transmit, then,

$$G = \frac{T}{R}$$

If no packets are generated, *G*=0.

2.8.4 Blocking Probability

Blocking probability is a common measure of the network performance. It is defined as the statistical probability that a connection cannot be established due to insufficient transmission resources in the network. It is expressed as a percentage or decimal equivalent of calls blocked by network congestion during the busy hour. Or it can be defines as the fraction of time that a service is denied due to insufficient transmission resources in the networks.

2.8.5 Data Throughput

Throughput is the total quantity of the packet that is successfully transmitted to the access point in a time interval. The normalized throughput by the data transmission data rate is represented as *S*. The throughput is usually measured in bits per second (bit/s or bps), and sometimes in data packets per second or data packets per time slot.

If the transmission data rate and the quantity of information in a packet are defined *R* (bps) and *T* (bits) and *n* packets are successfully transmitted in a time unit, *S* can be defined as:

$$S = \frac{T \times n}{R}$$

If no transmission packets are generated and all transmission packets are destroyed by collisions, *S* becomes 0. If all packets can be transmitted over all time units perfectly, the throughput becomes 1.

2.8.6 Loss Probability

Loss probability is an important quality of service (QoS) measure in communication networks. Losses that occur in the network are due to collisions when multiple stations transmit simultaneously and also due to environmental effects such as multipath, fading etc. Packet losses reduce the bandwidth between communicating stations, since they cause nodes to double their contention window and thereby, backoff for longer durations before retransmitting their data. It is defined as the ratio of the number of lost packets to the total number of packets transfer attempts during a specified period.

2.8.7 Transmission Delay

The period from which a packet is generated at an access point, transmitted to the access point and received at the access point is called the average transmission delay. It is dependant of the length of the packet, and is represented or shown as *D*.

2.8.8 Dropping probability

It generally refers to the phenomenon of call/packet dropping in both voice and data networks. Call/packet dropping refers to the event described as the termination of calls in progress before either involved party intentionally ends the call.

2.9 Simulation Model for PLC MAC Layer

2.9.1 Generic model for PLC MAC layer

The simulation model for MAC protocols is shown by fig. 2.18 below. There are number of bidirectional transmission channels that connect network users/subscribers with the base station. The transmission channel can be accessed by all network stations in the uplink transmission direction (shared medium) while the base station controls the downlink. The subscribers are represented by the network stations which provide different telecommunications services. All features of the MAC layer and protocols, including multiple access schemes are implemented by network stations and base stations (Hrasnica *et. al*., 2004).

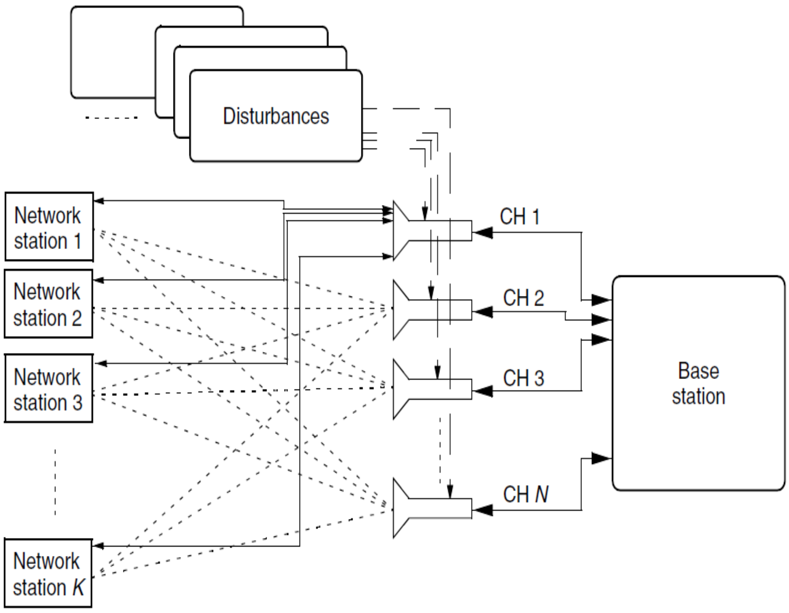

Figure 2.18: PLC Simulation Model (Source: Hrasnica *et. al.*, 2000)

2.9.2 Disturbance Modeling

The disturbances in PLC networks can be represented by an on–off model (Hrasnica *et. al.*, 2004):

- OFF – the channel is disturbed and no transmission is possible, and
- ON – the channel is available.

These two states are modeled by two random variables that represent interarrival times and durations of the disturbances. Both random variables are assumed to be negative exponentially distributed. The following three disturbance scenarios are used for investigations:

- Disturbance-free network,
- Lightly disturbed network – 200 ms mean interarrival time of the impulses/disturbances,
- Heavily disturbed network – 40ms mean interarrival time of the disturbances.

2.10 Summary

This chapter gives the details of powerline communications. The structure of PLC, the PLC network, and the different multiple access protocols including fixed multiple access and random access techniques are discussed. Also the different parameters which are used to evaluate the performance are mentioned. The simulation model is also discussed. Chapter 3 gives the modeling of powerline channel for performance evaluation.

CHAPTER 3

MODELING OF PLC MAC LAYER

3.1 Introduction

A multiple access scheme establishes a method of dividing the transmission resources into accessible sections, which are used by multiple subscribers using various telecommunications services. Normally a multiple access scheme is applied to a transmission medium (e.g. wireline or wireless channel) within a particular frequency spectrum, which can be used for information transfer. In the case of multiple subscribers using a shared transmission medium, telecommunications signals (information patterns) from individual users have to be transmitted within separated accessible sections, provided by a multiple access scheme, ensuring error-free communications. But a MAC protocol applied to a network with multimedia traffic, such as PLC, has to ensure sufficient QoS for different kinds of telecommunications services and for good network utilization. Therefore, in this chapter in order to compare the performance of various protocol solutions in accordance with QoS level, which can be provided by their application a PLC MAC layer model valid for this study, is selected.

The model will be applied for performance evaluation of two multiple access techniques by using several uplink architectures. The multiple access techniques to be considered are TDMA and FDMA, where the total channel capacity is divided into a fixed number of equal-capacity subchannels. In the model real-world parameter assumptions in the context of packet networks are taken into account. The parameter will be useful during the performance analysis in order to develop intuition about the effectiveness of the different architectures.

3.2 Modeling Technique

The performance analysis of a communications network and the evaluation of QoS parameters, such as the relevant QoS parameter defined for this investigation, can be carried out by the following three methods (Hransica *et. al.*, 2004):

- measurements,
- analytical modeling, and
- simulation modeling.

Simulation modeling is chosen as the primary analysis method in this investigation for the following reasons (Hransica *et. al.,* 2004):

- complexity of the MAC protocols,
- variety of applied disturbance and traffic models,
- fair performance comparison of different protocol solutions, and
- the possibility of a detailed investigation of the protocol implementation.

3.3 Simulation Model

The simulation model, selected for the investigation of MAC protocols in this study is as shown in chapter 2 (Sec. 2.9.1), the model represents an FDMA/TDMA scheme. The model represents bi-directional transmission channels that connect network users/subscribers with the base station, which lead to the FDD mode, with symmetric division of data rates between uplink and downlink transmission directions. The transmission channels can be accessed by all network stations in the uplink transmission direction (shared medium) while the downlink is controlled by the base station. But for this study only the uplink is considered. This model is chosen because it provides the possibility for modelling;

- various disturbance types, which can be implemented to affect both single and multiple transmission channels and
- representation of different types of noise
- network stations that provide multiple telecommunications services (e.g. telephony and Internet).

In the model network stations represents subscribers and network stations and base stations implement all features of the investigated multiple access scheme. Though the generic simulation model is designed to represent the OFDMA/TDMA scheme, it can easily be adapted to represent a TDMA system as well as any combination of TDMA and FDMA methods.

3.4 Disturbance Modeling

The disturbances in PLC networks can be represented by an on–off model (Hransica *et. al.*, 2004):

- OFF – the channel is disturbed and no transmission is possible, and
- ON – the channel is available.

These two states are normally modelled by two random variables that represent interarrival times durations of the disturbances. In addition both random variables are always assumed to be negative exponentially distributed. However since the simulator for this study is Discrete-Event-Simulator (a channel can be in two states ON or OFF, time parameters are not considered), then all state are modelled by a single random variable.

The random variable represents the duration of a disturbance impulse with mean duration set to 100µs and it is assumed that the noise impulses with a duration shorter than 300µs do not cause transmission errors (e.g. owing to symbol duration, FEC etc). In this investigation, the disturbances are modelled independently for each transmission channel and following three disturbance scenarios are used in further investigations;

- low disturbance network - 20µs mean duration of the impulses/disturbances,
- medium disturbed network - 60µs mean duration of the impulses/disturbances,
- heavily disturbed network - 100µs mean duration of the impulses/disturbances.

3.5 Subscriber Modeling

Network stations implemented in the simulation model (Fig. 2.18) can be connected with a number of traffic models, to represent different telecommunications services or various service classes. Primary telecommunications services, Internet-based data transmission and telephony, representing a packet switched and a circuit switched service respectively, can be implemented in the simulation model, as shown in Fig. 3.1. For data user models the packets (e.g. IP packets) from the data traffic source are delivered to the packet queue of the network station. Later, the packet is segmented into segments, which are stored in the transmission queue. Both packet and transmission queues can store a number of packet (or segments of a packet). So, a maximum of n user packets can be stored in the network station. After successful transmission of the packet, the next packet (if any) is moved from the packet to the transmission queue. Later, the reservation procedure is carried out for the new packet. The data source generates user packets according to an applied traffic model. After each packet generation, the data source calculates a time for the generation of a new packet. If the packet queue is occupied, the data source is stopped and it can deliver the new packet after the packet queue is empty again. This investigation implements a user model for telephony service only therefore user model for data will not be discussed further.

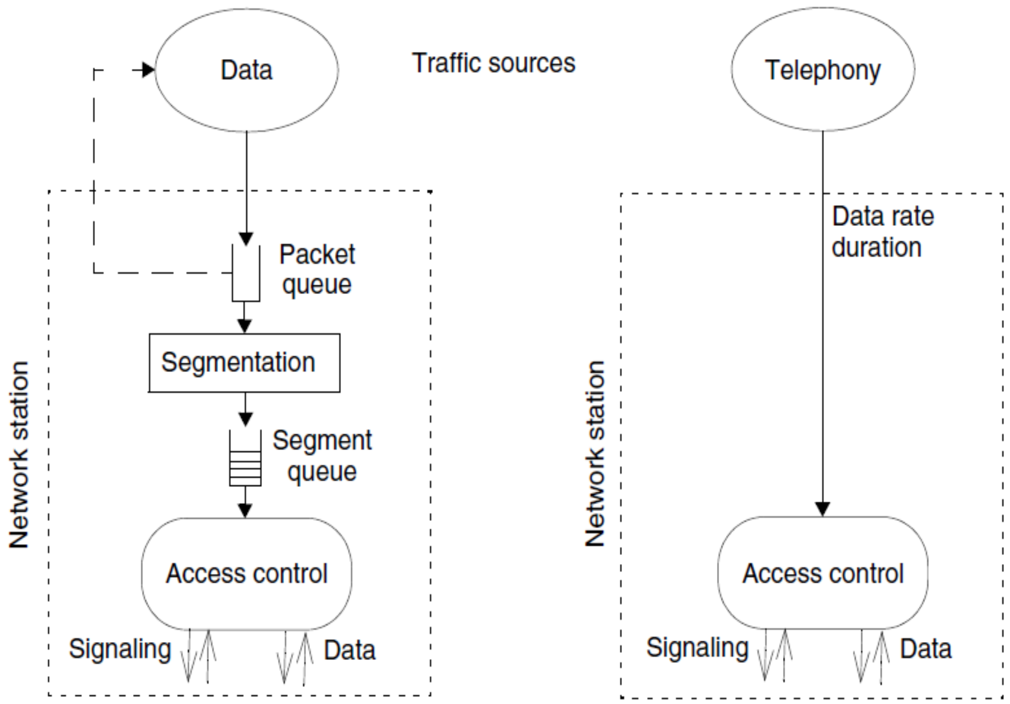

Figure 3.1: User models for data and telephony service (Source; Hransica et. al., 2004)

For the implementation of the telephony service calls are generated in accordance with a traffic model for the telephony specified in fig. 3.1. The service provides circuit switched service (CS), without data reservation procedure such as that for the data service. It assumed that once the station generates data it is establishing the connection, therefore the no signalling procedure is carried out. The telephony service for this study applies in-band signalling due to the fact that packet generation is combined with connection requests.

3.6 Traffic Modeling

Number of traffic models, can be found in different telecommunications services or various service classes such as;

- Telephony traffic models,
- Internet traffic models, and
- Multimodal traffic models.

According to Hransica *et. al.*, 2004 the arrivals of the voice connections seem to be in a range of minutes, whereas the data packets, for example, caused by an Internet connection, are generated in a range of seconds. Thus, it can be recognized that the arrival rate of the voice connections is significantly lower when compared with arrivals of IP packets. Accordingly, the arrival rate of the transmission requests for data transmissions is much higher than in the case of telephony. Therefore, the requests for telephony connections can be omitted in this investigation and they are not particularly modelled.

3.6.1 Internet Traffic Models

Data traffic is characterized by two random variables; mean packet size and interarrival time of packets. To define a simple model for Internet-based data traffic, the mean packet size is set to 1500 bytes in accordance with the maximum size of an Ethernet packet. The mean interarrival time of packets represents user requests for download of WWW pages and it is chosen to be 4.8 s. So, the average data rate per subscriber amounts to a relatively low value of 2.5 kbps.

3.6.2 Multimodal Traffic Models

In uplink architectures, a big part of the traffic load in the uplink belongs to the WWW requests. The size of the IP packets carrying WWW requests is differently specified in various traffic models; for example, between 64 bytes (HoudtBl00, Hransica *et. al.*, 2004) and 344 bytes (TrabCh, Hransica *et. al.*, 2004). The share of manually generated requests swings between 10 and 50% of all packets in the uplink, and the part of the automatic request is between 38 and 88% (Arli, Hransica *et. al.*, 2004). Other types of packets transmitted in the uplink as well as in the downlink are the control packets. The size of the control packets, which are mainly caused by the transmission of acknowledgments used in the TCP protocol, is considered to be between 40 and 92 bytes (TrabCh, Hransica *et. al.*, 2004). The multimodal traffic models characterize the IP traffic caused by WWW applications.

3.7 Implementation and Parameters of the Simulation Model

The simulation model used in this investigation is implemented using MATLAB, one of the most popular computer simulation languages in the world. In chapter 3 (section 3.5), it is concluded that the consideration of the telephony service is not relevant for this study. Since the telephony service applied in modelling subscribers uses circuit switched transmission channels provided by the FDMA and TDMA schemes, therefore for this investigation, it was assumed that one half of the network capacity is occupied by services using the circuit switched channels (including telephony). The remaining network capacity is occupied by the services using packet switched transmission channels.

Recent PLC access networks provide data rates of about 2Mbps. If the data rate of a transmission channel is set to 64 kbps, there will be approximately 30 channels in the system. Accordingly, the number of packet switched channels in the model is 15, which results in 960 kbps net data rate in the network (Tab. 3.1). The duration of a time slot provided by the TDMA scheme is set to 4 ms in the simulation and model. Within 4ms, a 64-kbps transmission channel can transmit a data unit of 32 bytes. Accordingly, the size of a data segment is also set to 32 bytes. It was also assumed that the entire segment is used for carrying payload.

Table 3.1 Simulation Model Parameters

Parameter	**Value**
Number of channels	40-50
Channel data rate	64Kbps
Time Slot duration	4ms
Segment/Payload size	32 bytes

The duration of a simulation run is chosen to correspond to the time needed for at least 10,000 events (generated packets) in the network.

3.8 Channel Assignment and Scheduling Algorithms

3.8.1. Channel Assignment Algorithms

For efficient utilization of the radio spectrum, a channel assignment strategy is required with the objectives of increasing capacity and minimizing interference. A variety of channel assignment strategies exists and they can either be classified as (Rappaport, 2002);

- Fixed channel assignment or
- Dynamic channel assignment.

The choice of channel assignment strategy impacts the performance of the system as to how packets generated by stations are handled. In FCA a base station is allocated a predetermined set of TDMA/FDMA channels, such that once the packet is generated it can only be served by an unused channel. If all channels are occupied, the packet is blocked and the station is denied from service.

In DCA, channels are not allocated to the base station permanently. Instead each time a packet generation is made, the base station requests channels from the switch. The switch then allocates a channel to the base station following an algorithm that takes into account the future likelihood of future blocking et cetera. DCA reduces the blocking probability, which increases trunking capacity of the system. This is due to the fact that, all channels in the system are accessible by all base stations. Besides the advantages of DCA this investigation uses FCA for channel assignment for the base station because;

- The PLC network considered is assumed to have number of stations that can be served by a single base station, and
- All the stations are located within the same PLC network.

3.8.2. Scheduling Algorithms

Once the channel assignment strategy is decided a mechanism for allocating channels to stations must be established. There are number algorithms that can be employed such as;

- First-Come First-Save, and
- Round Robin.

The majority of scheduling algorithms consider messages based on message characteristics such as length, the amount of time that the message has been in the system, and the amount of service so far received by the message. With static scheduling, message priority does not change with time. Dynamic scheduling algorithms however can change a message's priority value based on the amount of time that the message has spent in the system, or the amount of service already received by the message. Additionally, scheduling algorithms can be non-preemptive or preemptive, where message transmissions can be interrupted by messages of higher priority.

First-Come First-Serve algorithm, it is a simple non-preemptive static scheduling algorithm. In this algorithm the message are served in order of their arrival. The disadvantage of this algorithm is that it is unfair to short messages.

Round-Robin algorithm, it can overcome the shortcoming of FCFS. In this scheme, messages are generally divided into smaller packet sizes and are served one packet at a time in a round-robin fashion, rotating among the messages. Short messages no longer need to wait for the complete transmission of a long message. However, round robin scheduling can result in large delays when there are many messages in the system. Moreover it requires packets to be buffered at the stations.

In this study fixed-length messages are considered, therefore packets are transmitted by using FCFS. Fixed length messages and FCFS remove the need to implement buffers providing the environment that can be supported by the telephony service. The telephony service was employed to model the subscriber or users by Simulator applied in this study.

3.9 PLC Network

The PLC network model considered consists of a base station (BS), which is located at a transformer station and connected to the backbone communication networks. The number of subscriber stations (SSs) is interconnected with each other and with the BS via the power line transmission medium. Figure 3.2 depicts the PLC Network considered in this investigation (Bianchi *et. al.*, 2003).

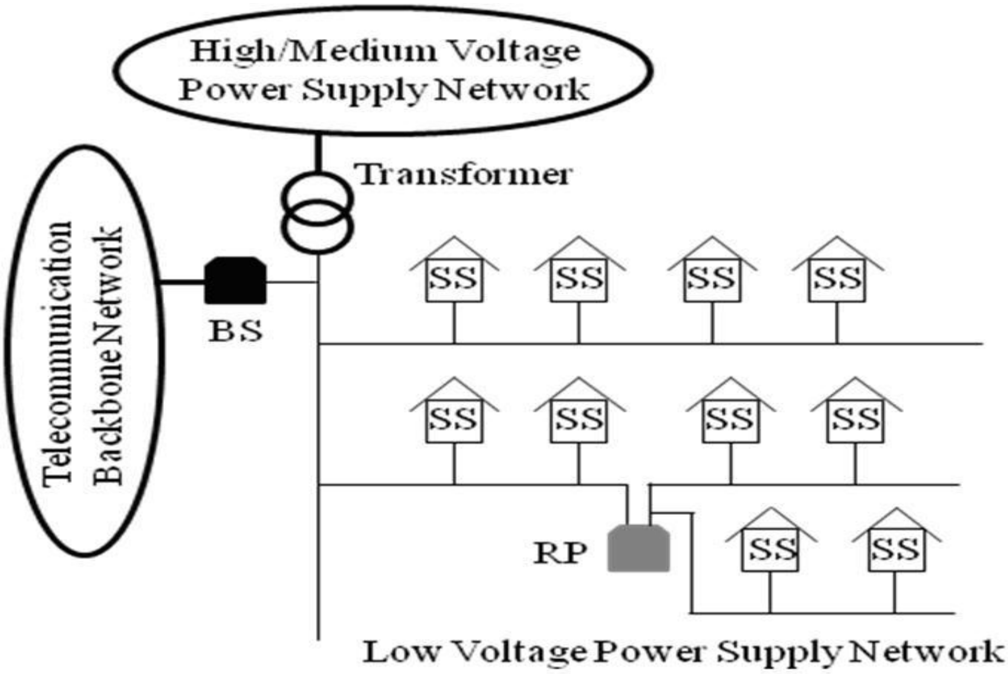

Figure 3.2 : PLC Network (Source: Bianchi *et. al.*, 2003)

The PLC access network is in the range of a low-voltage power supply network, as shown in fig. 3.2. It consists of;

- BS, which is located at a transformer station and connected to a backbone telecommunication network, and
- Number of subscriber stations (SSs), say *N* that are interconnected with each other and with the BS via the power lines.

Depending on the location, the transformer station distributes power to the covered low-voltage power supply network and receives power from a medium-voltage or high-voltage power supply network. When an SS is located near the BS, the communication can be organized directly between the SS and the BS, otherwise, one or more repeaters (RPs) may be embedded inside the network to compensate for signal attenuation. The RP is used for increasing signal strength when it falls below some predefined value.

The BS is an access point for the communication between a subscriber of the PLC network and a user of an external network. Also it provides the communication between the subscribers inside the PLC network. The signal transmission directions in a PLC network include downlink from the BS to the SSs and uplink from an SS to the BS.

3.10 Summary

In this chapter the methods for modeling MAC layer are analyzed that is, measurement, analytical and simulation modeling. Simulation modeling is chosen as the method of modeling the MAC layer for performance of multiple access schemes. The simulation model selected is also discussed. The model represent bidirectional transmission channel that connect network users/ subscribers with the base station. The traffic and subscriber modeling is also discussed. MATLAB is the tool that is going to be used for simulation modeling. The fixed channel assignment (FCA) and dynamic channel assignment (DCA) are the methods which are used for channel assignment. For this research the fixed channel assignment is used. Chapter four explains the performance of the multiple access schemes.

CHAPTER FOUR

PERFORMANCE EVALUATION OF MULTIPLE ACCESS SCHEMES

4.1. Introduction

In this chapter, the performance of FDMA and TDMA are considered as solutions for the MAC layer to be applied to PLC access networks. The MAC layer is a common component in every telecommunications system with a shared transmission medium. There are various realizations of the MAC layer and its protocols that are developed for particular communications networks, depending on their specific transmission features, operational environment, and their purpose. PLC access networks are characterized by a special transmission medium (low-voltage power supply network) that provide limited data rates. Limited data rates are caused by the presence of noise in powerline channels causing disturbances for data transmission. To ensure the competitiveness with other access technologies, PLC has to offer a wide range of telecommunications services and satisfactory QoS.

4.2. Network Load Variation

A performance evaluation of various solutions for the multiple access techniques for MAC layer has to be carried out in network models with varying traffic conditions. To vary the network load and the number of network stations can be increased from 50 to 500. This results in a minimum average network load of 125 kbps and a maximum of 1.25 Mbps, in accordance with the internet traffic models presented in chapter 3 (section 3.5.1). Another approach to the increase of the network load is a variation of offered traffic for individual network stations; for example, the offered network load of individual network stations can be varied from 2.5 to 25 kbps for a constant number of stations, which results in the same common offered network load, as in the first case. If the number of stations remains constant, the interarrival times of the user packets has to be reduced to increase the network load. That means, for a network load of 1.25 Mbps and 50 network stations, the inter-arrival time has to be set to 480 ms in the simple traffic model with rare requests and to 96 ms in the model with frequent requests. For this study network load variation was achieved by varying offered traffic for network stations, and then carried traffic and packet loss ratio were calculated for each offered traffic. The calculated values were used in determining and comparing the performance of TDMA and FDMA system.

4.3 Effect of Channel Disturbances on FDMA System

The communication systems designed for power-line networks suffer from different disturbances caused by the powerline channel. This is caused by the fact that, power supply networks are designed for energy distribution and not data transmission. The transmission characteristics of powerline channels are not favourable for data transfer owing to the variance of impedance caused by the variety of appliances that could be connected to the power outlets. As these have been designed for energy distribution and not for data transmission, there are unfavourable channel characteristics with considerable noise and high attenuations. Because it is always time varying, the powerline can be considered a multipath channel that is caused by the reflections generated at the cable branches through the impedance discontinuities. Noise especially impulsive noise is one of the impairments that require a great deal of attention because it affects the performance of the PLC MAC layer directly.

To determine the influence of channel disturbances in FDMA multiple access techniques, two scenarios for each were considered. One being FDMA fixed number of channels under different channel disturbances. The other is FDMA variable number of channels under fixed channel disturbance. For variable number of channels, fixed channel disturbance the channel was considered to be heavily disturbed. While for variable disturbance, fixed number of channel the channel was considered under low, medium and heavy disturbance respectively.

4.3.1 Fixed number of Channels

The PLC MAC layer with FDMA as a multiple access techniques was considered. The number of channels was set to 50, and then the channel disturbance was varied. The variations considered were low, medium and high channel disturbance. These disturbances are changed by varying the mean duration of the impulses or disturbances from 20µs to 100µs in an interval of 40µs. As it is stated in chapter 3 (section 3.3) 60µs was the mean duration of the impulses or disturbances for this study. This implies that, bellow and above this value the channel presents low and high channel disturbances respectively. Thereafter the simulation was run while offered traffic and packet loss ratio are calculated. Fig. 4.1 shows the performance of the FDMA system with 50 channels at different channel disturbances. It is observed that for all channel disturbances the good performance is obtained when the channel presents low disturbances. For instance given the traffic load of 0.5 the packet loss ratio is 0.033, 0.15 and 0.51 for low, medium and high channel disturbances respectively. The good performance is obtained when the channel presents low disturbances because more packets are able to go through the channel.

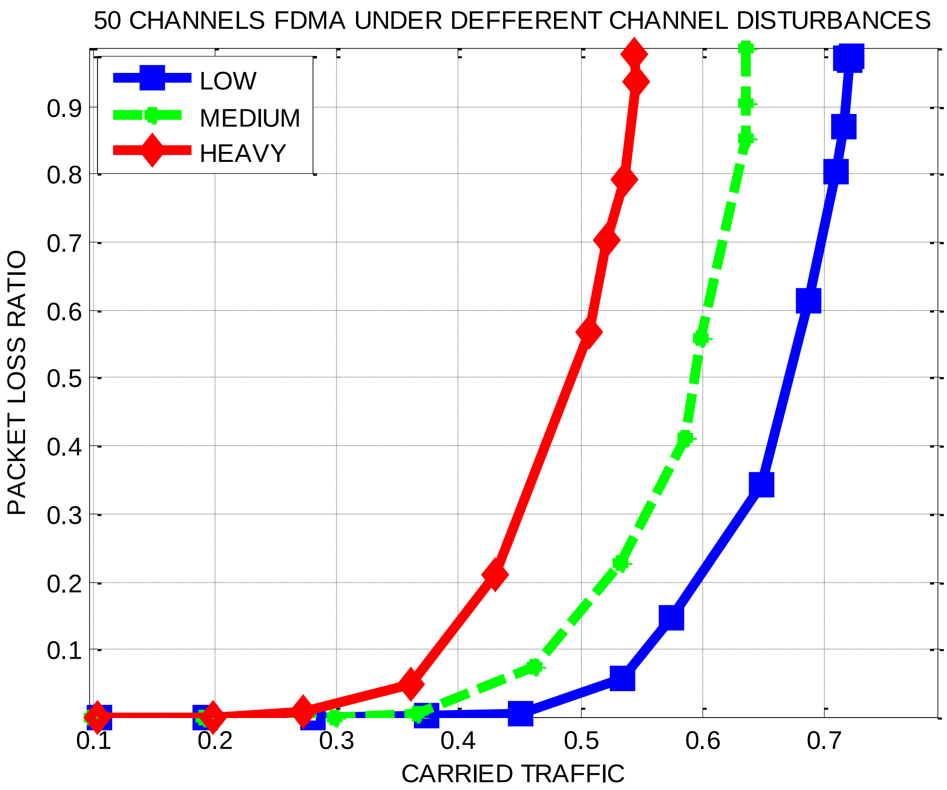

Figure 4.1: 50 Channels FDMA under different conditions

4.3.2 Variable number of Channels

The PLC MAC layer with FDMA as a multiple access techniques was considered. The heavy channel disturbance was selected, and then the number of channels was varied. The channels were varied from 40 channels to 50 channels in an interval of 5 channels. This was done to check if the increase of number channels as the effect on the packet loss ratio. Thereafter the simulation was run while offered traffic and packet loss ratio are calculated. Figure 4.2 shows the performance of the FDMA system with a heavy disturbed channel at different channel number of channels. It is observed that the good performance is obtained when the number of channels is 50. For instance given the traffic load of 0.4 the packet loss ratio is 0.1, 0.35 and 0.55 for a 50, 45 and 40 channels FDMA system respectively. The good performance is obtained when the number of channels is 50 because, there is a high probability of find a disturbance free channel in the system. Hence more packets are able to go through the channel.

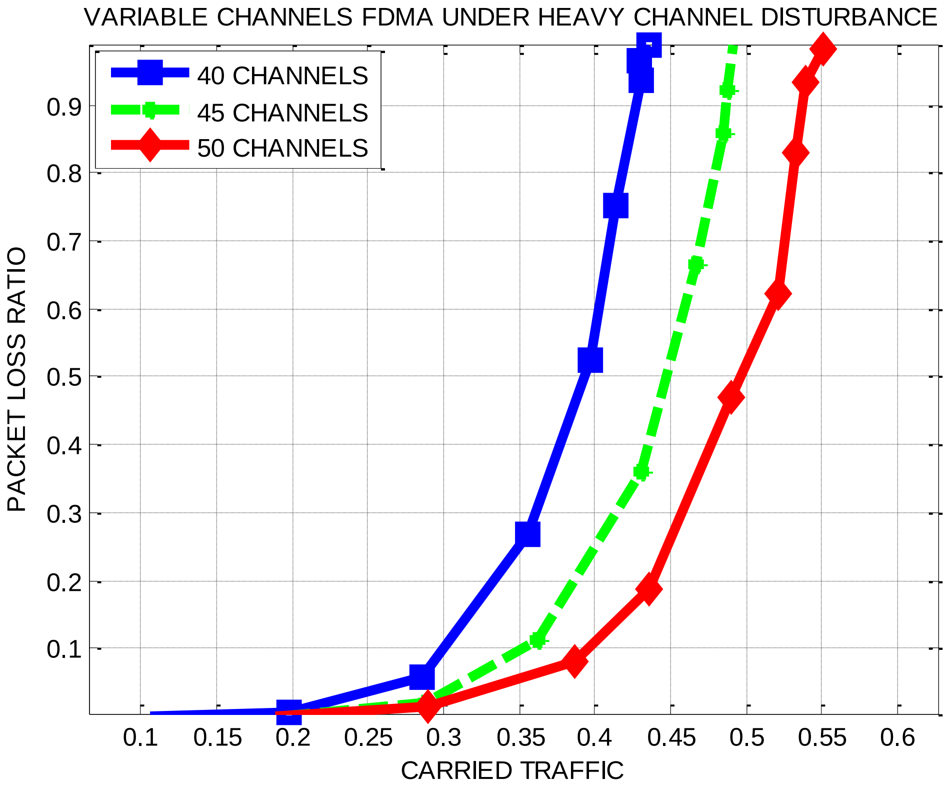

Figure 4.2: Variable Channels under Heavy Channel Disturbance

4.4 Effect of Channel Disturbances on TDMA System

To determine the influence of channel disturbances in TDMA multiple access techniques, two scenarios for each were considered. One being TDMA fixed number of channels under different channel disturbances. The other is TDMA variable number of channels under fixed channel disturbance. For variable number of channels, fixed channel disturbance performance the channel was considered to be heavily disturbed.

4.4.1 Fixed number of Channels

The PLC MAC layer with TDMA as a multiple access techniques was considered. The number of channels was set to 50, and then the channel disturbance was varied. The variations considered were low, medium and high channel disturbance. These disturbances are changed by varying the mean duration of the impulses or disturbances from 20µs to 100µs in an interval of 40µs. As it is stated in chapter 3 (section 3.3) 60µs was the mean duration of the impulses or disturbances for this study. This implies that, bellow and above this value the channel presents low and high channel disturbances respectively. Thereafter the simulation was run while offered traffic and packet loss ratio are calculated. Figure 4.3 shows the performance of the TDMA system with 50 channels at different channel disturbances. It is observed that for all channel disturbances the good performance is obtained when the channel presents low disturbances. For instance given the traffic load of 1 the packet loss ratio is 0.001, 0.05 and 0.25 for low, medium and high channel disturbances respectively. The good performance is obtained when the channel presents low disturbances because; there is a highest probability of finding the channel in good conditions. Hence more packets are able to go through the channel.

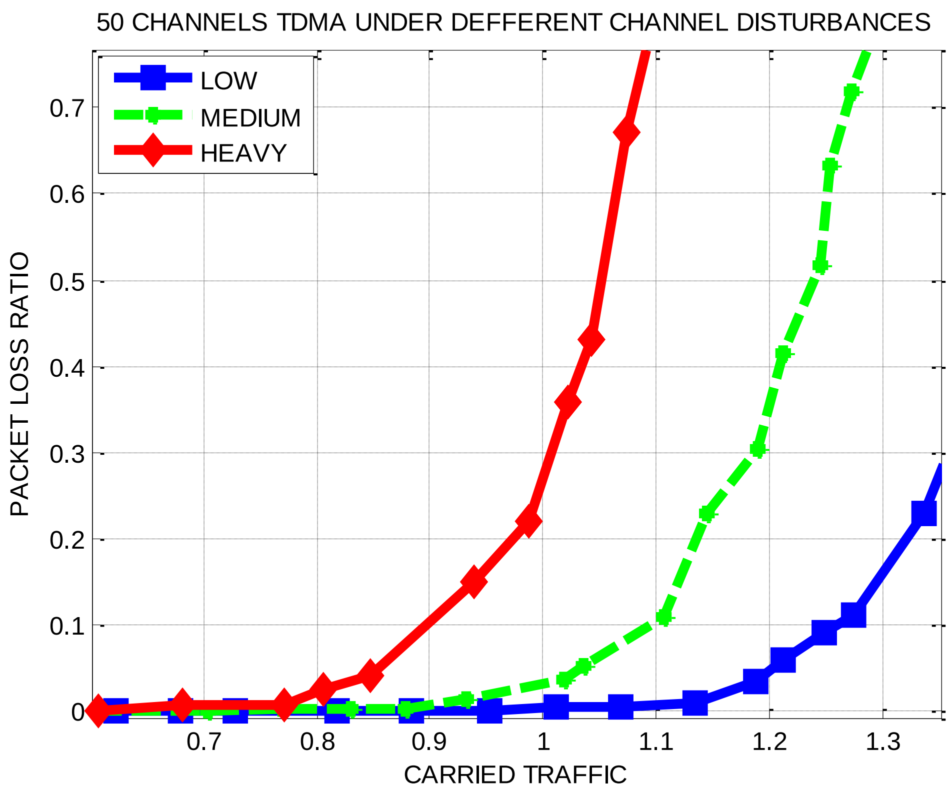

Figure 4.3: 50 channels TDMA under different channel disturbances

4.4.2 Variable number of Channels

The PLC MAC layer with TDMA as a multiple access techniques was considered. The heavy channel disturbance was selected, and then the number of channels was varied. The channels were varied from 40 channels to 50 channels in an interval of 5 channels. This was done to check if the increase of number channels as the effect on the packet loss ratio. Thereafter the simulation was run while offered traffic and packet loss ratio are calculated. Figure 4.4 shows the performance of the TDMA system with a heavy disturbed channel at different channel number of channels. It is observed that the good performance is obtained when the number of channels is 50. For instance given the traffic load of 0.8 the packet loss ratio is 0.033, 0.125 and 0.375 for a 50, 45 and 40 channels FDMA system respectively. The good performance is obtained when the number of channels is 50 because, there is a high probability of find a disturbance free channel in the system. Hence more packets are able to go through the channel.

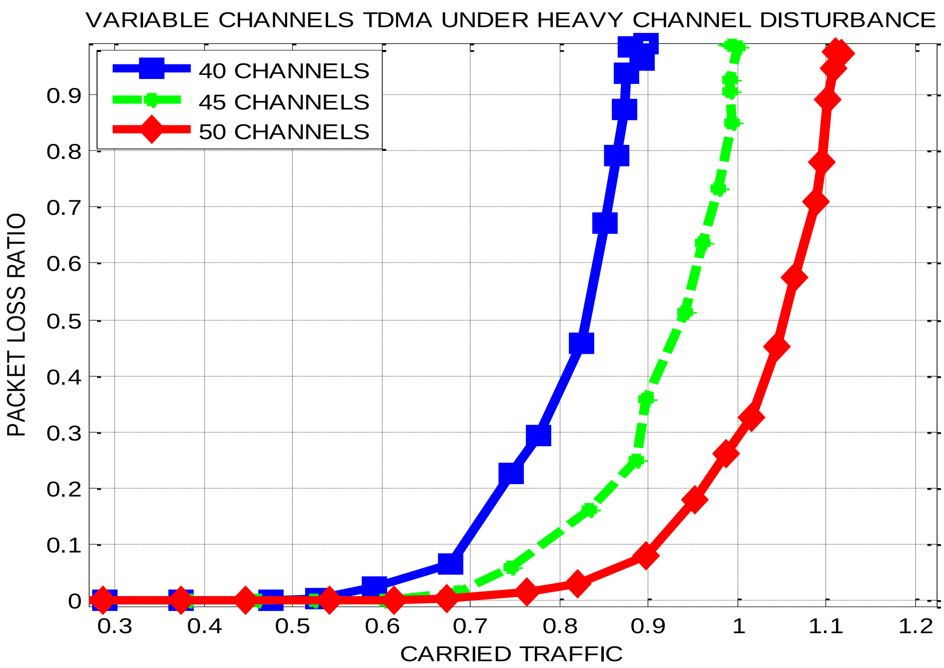

Figure 4.4: Variable channels TDMA under heavy channel disturbances

4.5 FDMA and TDMA Performance Comparison

By comparing simulations of the FDMA and TDMA system it is observed that the performance of TDMA system under fixed number of channels, variable channel disturbances and fixed channel disturbance, variable number of channels surpasses that of FDMA. This is because for any configuration of channels TDMA has more number of channels. For example when the number of channels is 50 and channel disturbance is heavy TDMA system sustained a traffic load of 1 while the FDMA system sustained a traffic load of 0.452 with the same packet loss ratio. The packet loss ratio under this observation was 0.275. Given similar considerations it can be concluded that the TDMA system performs better, because reducing packet loss ratio means more capacity (A system can carry more users).

In TDMA the channels are divided along the time axis into non-overlapping channels, and each user is assigned a different cyclically-repeating timeslot. Therefore under the same number of channels, the actual number of channels in TDMA system is more compared to the FDMA system. This implies that there is a high probability of obtaining a disturbance free channel in the TDMA system than in the FDMA system. Hence more packets are able to go through the channel. But since TDMA channels occupy the entire system bandwidth which is typically wideband, some form of ISI mitigation is required. However, the cyclically repeating timeslots imply that transmission is not continuous for any user. Therefore, digital transmission techniques which allow for buffering are required. The fact that transmission is not continuous simplifies overhead functions such as channel estimation, since these functions can be done during the timeslots occupied by other users. Moreover in TDMA it is simple to assign multiple channels to a single user by simply assigning him multiple timeslots.

A major difficulty of TDMA, at least for uplink channels, is the requirement for synchronization among the different users. To maintain orthogonal timeslots in the received signals, the different uplink transmitters must synchronize such that after transmission through their respective channels, the received signals are orthogonal in time. This synchronization is typically coordinated by the base station or access point, and can entail significant overhead. Multipath can also destroy time-division orthogonality in both uplinks and downlinks if the multipath delays are a significant fraction of a timeslot. TDMA channels therefore often have guard bands between them to compensate for synchronization errors and multipath.

Further more in TDMA with cyclically repeating timeslots the channel characteristics change on each cycle. Thus, receiver functions that require channel estimates, like equalization, must re-estimate the channel on each cycle. When transmission is continuous, the channel can be tracked, which is more efficient. TDMA is used in the GSM, PDC, IS-54, and IS-136 digital cellular phone standards.

4.6 Summary

In this chapter the performance of FDMA and TDMA were found and compared. It was found that TDMA performs better than FDMA under different channel conditions. In the following chapter that is chapter five, conclusion about this research is going to be given together with some recommendations. Also further future researches are going to be stated.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

In this study, the performance of two multiple access techniques were investigated. The PLC MAC layer simulation model developed by Hransica *et. al.,* 2004 has been used to simulate a realistic PLC MAC layer. To determine the influence of channel disturbances in FDMA/TDMA multiple access techniques, two scenarios for each were considered: one being FDMA/TDMA fixed number of channels under different channel disturbances and the other is FDMA/TDMA variable number of channels under fixed channel disturbance. For variable number of channels, fixed channel disturbance the channel was considered to be heavily disturbed. While for variable disturbance, fixed number of channel the channel was considered under low, medium and heavy disturbance respectively. It was found that, the performance of TDMA system under fixed number of channels, variable channel disturbances and fixed channel disturbance, variable number of channels surpasses that of FDMA. For example when the number of channels is 50 and channel disturbance is heavy TDMA system carried a traffic load of 1 while the FDMA system carried a traffic load of 0.452 with the same packet loss ratio. The packet loss ratio under this observation was 0.275.

5.2 Recommendations

The results of this work have shown that the performance of TDMA system under different configuration surpasses that of FDMA. To maintain the same performance more channels should be employed in FDMA system. But in FDMA channels can be increased by increasing more carrier frequencies, this implies more bandwidth is required to carry the same traffic at the same packet loss ratio compared to TDMA system. Also besides the good performance provided by a TDMA system, the need for ISI mitigation, buffer requirements, synchronization and channel re-estimation on per slot basis complicates the TDMA communication system.

5.3 Suggestions for Further Research

For future work it is recommended researches for performance evaluation of other multiple access schemes such as the combination of OFDMA and TDMA (OFDMA/TDMA) must be done. Also the performance of CDMA considering direct sequence and frequency hopping must also be analyzed.

REFERENCES

Behrouz A. Forouzan (2007), Data Communications and Networking, McGraw-Hill.

Bianchi, G., Tinnirello, I. and Conigliaro, G. (2003), Design and performance evaluation of a hybrid reservation-polling MAC protocol for power-line communications. Int. J. Commun. Syst., 16: 427–445. doi: 10.1002/dac.597.

Bumiller G, "System Architecture for Power_Line Communication and Consequences for Modulation and Multiple Access", GmbH, Groβhabersdorf, technical paper for ISPLC, 2001.

Chan S. (2000),"Multiple Access Protocols for Multichannel Communication Systems", Masters Dissertation, Department of Electrical Engineering and Computer Science, Massachusetts Institute of Technology, Massachusetts, USA.

Goldsmith A, Wireless Communications, Cambrige University Press, 32 Avenue of Americas, New York, NY 10013-2473, USA, 2005.

Harada, H. and Prasad, R. (2002), Simulation and Software Radio for Mobile Communications, Artech House.

Hrasnica H., Haidine A. and Lehnert R.,"Broadband Powerline Communications Networks-Network Design", John Wiley & Sons, Ltd, 2004.

Hrasnica H and Lehnert R, "*Powerline Communications for Access Networks-Performance study of the MAC layer"* III International Conference on Telecommunications BIHTEL 2000 "Telecommunications Networks" – October 23-25, 2000 – Sarajevo, Bosnia and Herzegovina.

Hrasnica H., Lehnet R., " *Powerline Communications in Telecommunication Access Area (Powerline Communications im TK-Zugangsbereich)",* VDE World Microtechnologies Congress- MiCRO.tech 2000-ETG-Fachtagung und-Forum: Verteilungsnetze im liberalisierten Markt-September 25-27, 2000-Expo 2000, Hannover, Germany.

Hrasnica H. and Haidine A. "*Modeling MAC layer for Powerline Communications Nertworks*", internet, performance and control of networks systems, part of SPIE's symposium on Information Technologies, Boston MA,USA; 5-8 November,2000.

Hrasnica H., "MAC Layer in Broadband PLC Networks- State of the Art, Solutions and Modelling", November 5-8, 2000- Boston MA, USA.

Langfeld P, Zimmermann M and Dostert K, "*Powerline Communication System Design Strategies for Local Loop Access",* International Symposium on Powerline Communications and its application (ISPLC2000), Limerick, Ireland; 5-7 April, 2000.

Lucian Ngeze (2008), "Broadband over Powerline (BPL) Technology", a seminar report, Department of Electronics and Communication Engineering, University of Kerala, Kerala, India.

Rappaport Theodore S. (2002),Wireless Communications, Principles and Practice, Prentice hall communications engineering and emerging technologies series, Prentice Inc., ISBN 0-13-042232-0.

Srikanth S., Kumaran V. and Manikandan C. (2010) "Orthogonal Frequency Division Multiple Access: Is it the Multiple Access of the Future?" AU-KBC Research Center, Presented at NCC, IIT Madras.