Power Line Communications

Abdelraheem Mohamed Elkhalifa , Dr. Abdul rasoul J. Alzubaidi

[1] *Sudan Academy of Sciences (SAS); Council of Engineering Researches & Industrial Technologies,*
[2] *Electronic Dept- Engineering College –Sudan University for science and Technology*

ABSTRACT:

This paper is about power-line communication over the low-voltage grid, which has interested several researchers and utilities during the last decade, trying to achieve higher bit-rates and more reliable communication over the power lines.The main advantage with power –line communication is the use of an existing infrastructure. Wires exist to every household connected to the power – line network.This paper starts with a general introduction to power-line communication. Then an existing application, communicating on a low voltage grid is investigated in order to obtain some knowledge of how the power line acts as a communication channel. I did experiment to verify that result.The power line communication channel can in general be modeled as a system with frequency dependent signal-to-noise ratio varying with time over the communication bandwidth. Finally we describe the basic parts of the system that eventually could be used for information transfer over the power line communication channel.

KEYWORDS: *PLC, Transmissions, Modem, Modulations, Ethernet, Power, adapter, Socket, frequency, grid, Customers, electrical, computer, Internet.*

I. INTRODUCTION

In the last decade there was a large growth in small communication networks in the home &in the office places. Several computers & their peripherals interconnected together resulting the network to expand globally to the state of Internet. A number of networking technologies are invented which purely concentrates on home networks. But users are limited due to it is nature of high cost. Some are over engineered or difficult to install in pre-existing buildings. This paper is based on one such communication medium, which has a very high potential growth. I.e. the power line, which gives rise to power line carrier communication, refers to the concept of transmitting information using the main power line as a communications channel. Our project mainly aims at applicability of power line carrier communication techniques towards home networking.
Communication over the power line will have the following advantages:-

- The modem electric grids are well maintained & far superior to any of the wired communication networks.
- No. of electrical consumers are higher than telephone, cable or other wired communication customers. This will give a high potential market for the investors.
- The analog spread spectrum waves have much greater bandwidths or carrying capacity than the digital switched systems.
- Move your computers and appliances where you want.
- Utilizes existing power source for all your communications needs.
- Secure data –encryption.
- No more wires just plug in.
- Share your Internet connections.
  Also the communications over the power line will have the following limitations:-
- Electro-Magnetic Radiations Issues.
- Addressing Issues.
- Security.
- Noise Interference.
  Regulatory and Standardizations Issues

II.   PROJECT AIM

Power line carrier techniques would appear to be an economical and user –friendly method of installing a home network adapter in any building.This project explores such claim, investigating the challenges of using the power line for communication and to identify the possible methods to overcome these challenges. We expect to send a data from one computer to another computer through the existing domestic power line (Low Voltage).

2.1.Applications of power line network adapters
- High-definition (HD) and standard-definition (SD) video distribution.
- Broadband Internet sharing.
- Internet protocol Television (IPTV) and voice over Internet protocol (VoIP).
- Home Automation
- Automatic Meter reading
- Process Control
- Heating and Ventilation Control
- Air conditioning Control
- Lighting Control
- Status Monitoring and Control
- Low Speed data communication Networks
- Intelligent Buildings
- Fire and Security Alarm System
- Signs and Information Displays
- Power distribution Managements

III.   POWER LINE CARRIER CHALLENGES

Power lines and their associated networks are not designed for communication use. They are hostile environments that make the accurate propagation of communication signals difficult.Two of the biggest problem faced in using power lines for communications is excessive noise levels and cable attenuation. Noise levels are often excessive, and cable attenuation at the frequencies of interest is often very large. The most common causes of excessive noise in a domestic situation are the various household devices and office equipment connected to the network. Noise and disturbances on the power network include over voltages, under voltages frequency variations and so on. However, the most harmful noise for PLC applications is that superimposed on a power line. Switching devices such as light dimmers, induction motors in many common appliances and high-frequency noise caused by computer monitors and televisions often causes such superimposed noise.For a power line carrier communications system to perform reliably it must be able to avoid, or cope with, the different types of noise encountered on its communications channel. These different types of noise exist at different frequencies, and occur at unpredictable times. Thus, it is not sufficient to design a system that simply avoids using certain parts of the available bandwidth. Rather, a technique called frequency hopping can be used to overcome this problem. When a frequency –hopping communications system encounters noise at a certain bandwidth, it skips to a different bandwidth moving away from the original interference.
From the above definition the following points are represented a challenging technical problem in power line networks.

- Electrical wires were never designed for high speed transmission.
- Uncontrolled and (almost unpredictable) environment.
- Impedance mismatch causes strong multipath effect.
- Unknown, non –flat and non-stationary channel frequency response.
- Electrical devices connected to the network generate non- Gaussian, non- -white, non-stationary noise.
- Risk of EMC problems because of unshielded wires.

IV.   AVAILABLE BANDWIDTH & REGULATORY STANDARDS

Bandwidth available for power line communication is not limited by the physical capabilities of the line. Rather, regulatory authorities limit the available bandwidth for power line communication in order to prevent radio interference, other device interference and other such contentions. It is to be noted that bandwidth is proportional to the bit rate, thus a large bandwidth is needed in order to communicate with high bit rates. Various standards exist that provide regulations on the operating specifications of PLC systems. In our   project we use devices complies with part 15 of the Federal Communication Commission (FCC) Interference Statement rules. Operation is subject to the following two conditions:

■ This device may not cause harmful interference.
■ This device must accept any interference received, including interference that may cause undesired operation. Which is the European standard viz. CENELEC? The standard only allows frequencies between 3 kHz and 148.5 kHz. This puts a hard restriction on power –line communications and might   not be enough to support high bit rate applications, such as real-time video, depending on the   performance needed.

V.   MAC ENCAPSULATION

Unlike IEEE 802.11 frames, on which the protocol layers of the Wi-Fi technologies are based, the PLC frames can be considered as MAC encapsulations. Fig. 6.1 illustrates the MAC encapsulation of Home Plug 1.0 PLC frames. From the point of view of the data link layer, the MAC Ethernet frames are de-encapsulated from the physical frames for their presentation to the Ethernet interface of the PLC devices.
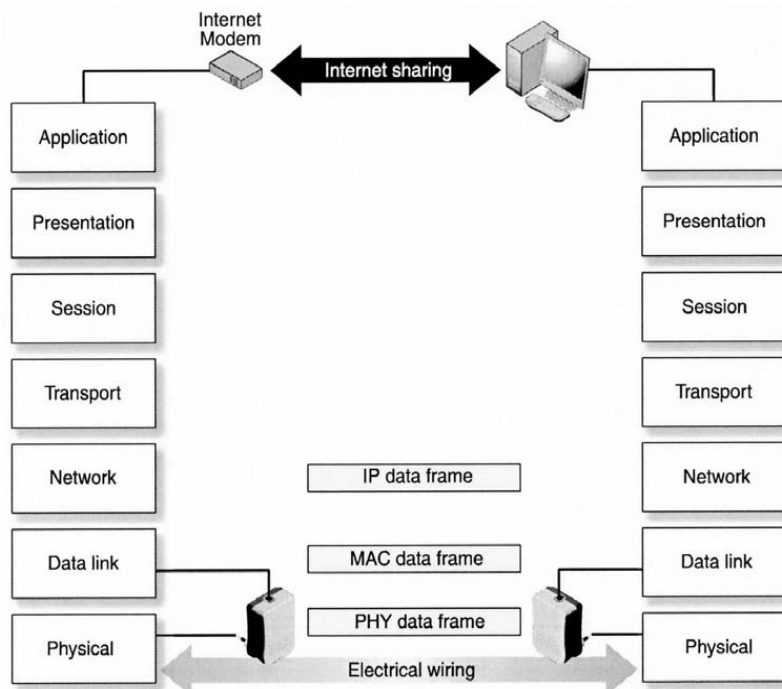
Fig. 6.1: PLC technologies and the OSI model.

VI.   PRACTICAL ISSUES

In designing the power line communication system we were to address even some the salient features. Modulation technique, transmission methods and so on were selected to give suitable performance in communication environment which we were expected to use.

4.1.Modulation Methods

The fundamental digital modulation techniques are based on keying.Phase –shift keying (PFK), a finite number of phase are used. In this form of modulation phase of the carrier wave is varied by a binary input stream. As the binary input signal changes from logic 0 to logic 1, and vice –versa, the PFK output shifts between two angles that are 180 degrees out of phase while keeping the frequency a constant.Frequency- shift keying (FSK), a finite number of frequencies is used. In this form of modulation carrier wave frequency is varied by a binary input stream. As the binary input signal changes from logic 0 to logic 1 and vice- versa, the FFK output shifts between two frequencies.Amplitude shift keying (ASK), a finite number of amplitudes is used.Quadrature amplitude modulation (QAM), a finite number of at least two phases, and at least two amplitudes are used.Due to the nature of high attenuation prevailing in the power line frequency shift keying and phase shift keying will give simpler results over others although both of them are robust.In order to decide the method of modulation to be used in power line communication it is important to keep in mind the hostile environment in which it operates.

It is difficult to say which method to use, whether FSK or PSK. Phase delay in the PLC channel is expected and unpredictable in the case of PSK technique. The reliable performance of FSK with the any reasonable amount of phase delay makes it modulation scheme of choice for PLC techniques.The difference between FM (frequency modulation) and PM (Phase modulation) is that the bandwidth is independent of signal bandwidth in FM, while it is strongly dependent on signal bandwidth in PM. Orthogonal Frequency Division Multiplexing Frequency division Multiplexing (FDM) is the technology that transmits multiple signals simultaneously over a single transmission path, such as a cable or wireless system. Each signal travels within its own unique frequency range (carrier), which is modulated by the data (text, voice, video, etc.).Orthogonal FDM's (OFDM) spread spectrum technique distributes the data over a large number of carriers that are spaced a part at precise frequencies. This spacing provides the "orthogonally" in this technique, which prevents the demodulators from seeing frequencies other than their own. Basic approach of OFDM is illustrated in the bellow fig. 7.1.
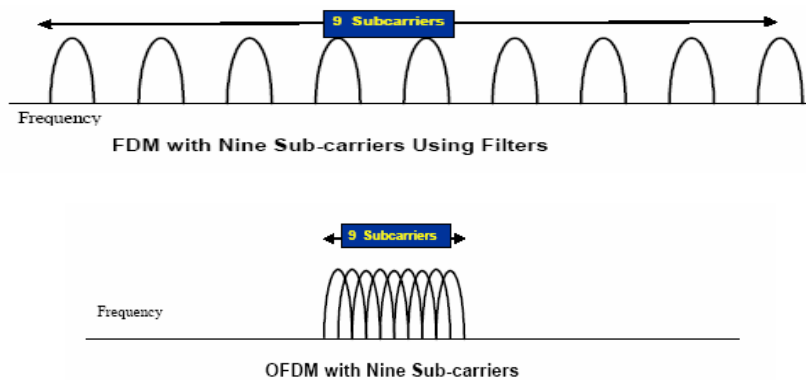

Fig. 7.1: Difference between band-width requirements in

FDM vs. OFDM.

OFDM is similar to FDM but much more spectrally efficient by spacing the sub-channels much closed together (until they are actually overlapping).This is done by finding frequencies that are orthogonal, which means that they are perpendicular in mathematical senses allowing the spectrum of each sub-channel to overlap another without interfering.
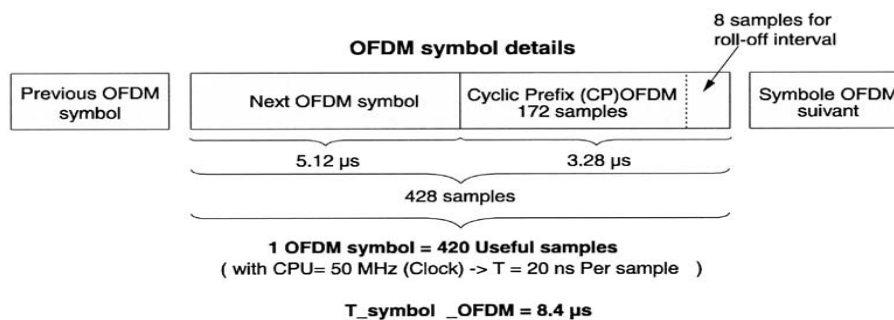

Fig. 7.2: OFDM symbol details.

The Coupling Network

A coupling circuit is used to connect the communication system to power line. The purpose of the coupling circuit is two- fold. Firstly, it prevents the damaging 50 Hz signal, used for power distribution, to enter the equipment. Secondly, it certifies that the major part of the received/transmission signal is within the frequency band used for communication.
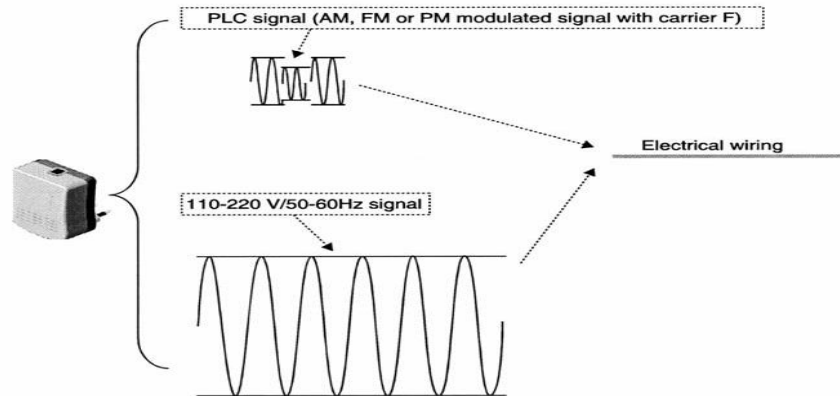
**Fig. 8.1: Sum of the modulated PLC signal and the power signal
(for example, 110 -220V/50-60 Hz).**

These increase the dynamic range of the receiver and makes sure the transmitter introduces no interfering signals on the channel. Thus ultimate coupler network design becomes a compromise between the different characteristics for receive and transmit direction, plus impedance.

Different ways exist in order to couple a communication device in to an electrical power line. Two main categories can be described as below.

Differential mode coupling: In this case the line or active wire is used as one terminal, and the neutral wire as the second terminal. In cases where a neutral line is not present (high voltage network), the ground line acts as the second terminal.

Common mode coupling: In this case the line (active) wire and neutral wires are used together forming one terminal and the ground wire serves as the second terminal. One might think this coupling mode is impossible, due to the connection of neutral and ground wires at the transformer.

In practice, the inductance between points of coupling and the short- circuit point is large enough to allow signal transmission. However, problems exist in using common mode coupling in the presence of earth leakage protection devices, and certain countries do not allow common mode coupling because of perceived dangers to customers.

Considering the physical implementation of the coupling two can be identified.

Capacitive coupling: A capacitor is used to couple the communication signal on to the power line.

Inductive coupling: An inductor is used to couple the communication signal on to the power network. Inductive coupling provides a physical separation between power network and communications network, making it safer to install.

In the electrical field, coupling can be defined as how two electrical circuits connect together in order to generate an electron flow between these two circuits. This electron flow is conveyed by an electric and a magnetic field created between the two electrical circuits due to their inductive and capacitive nature.

Inductive coupling is much more efficient than capacitive coupling. It is uses the electromagnetic induction method between two electrical wiring and a coil wound around this wiring. An inductive coupler reduces the attenuation by 10 to 15 dB for some frequencies in comparison with a capacitive coupler. The attenuation between the outlet and the switch box varies from 10 to 30 dB It is maximum between 15 MHz to 20 MHz. In the field of PLC networks, the injectors are devices used to connect a PLC device to the electrical network via an inductive coupling directly a round electrical wirings, for example, at the level of the electrical switchboard of a building.

Fig.8.2 illustrates the principle of a PLC signal injector consisting of the two following elements.
1. A magnetic coil wound around the natural cable of electrical network. As we know the neutral cable is the most interesting cable for the injection of the PLC signal over an electrical network, since it is distributed over all the electrical equipment.
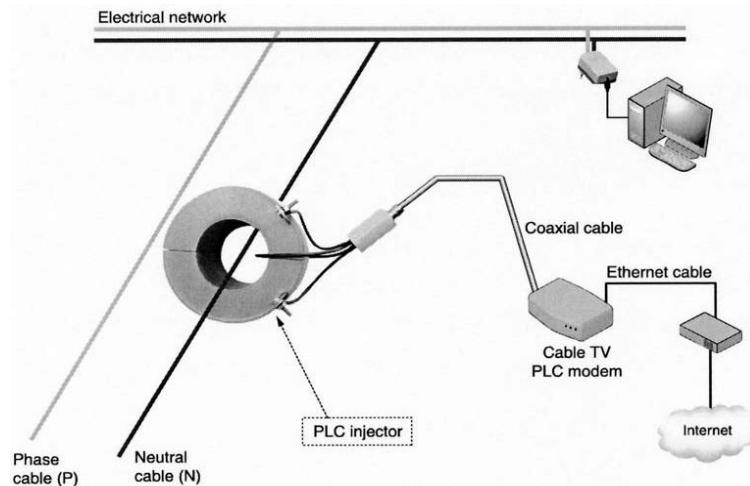2. A cable TV modem connected by a cable (for example, a coaxial cable) to the magnetic coil.

**Fig. 8.2: PLC signal injection by inductive coupling with coil
over a single phase network.**

Choice of injection cable

It is preferable to inject the signal over the neutral cable for a single –phase network and on one of the phase for a three –phase network. Better performance is achieved by injecting the signal over a single cable than over several cables at the same time. This method for connecting PLC devices requires access to the electrical wirings of 110 to 220/50 to 60 Hz network, unlike capacitive coupling, which is restricted to the connection of a device to an outlet. Therefore, it is important to knowledge of the electrical hazards close to the cables and components of the electrical network. Our project is focused with using two power line adapters, connected with two computers in peer-to-peer mode.

Master –Slave mode : Fig. 9.1a illustrates the architecture of an LV (Low Voltage) PLC network for electrical distribution in the master- slave mode. We find the master device at the ML/LV (medium voltage to low voltage) transformer level. This device checks the good working order of the PLC network and more particularly the existing network links with the slave devices located between the electrical meters of houses.
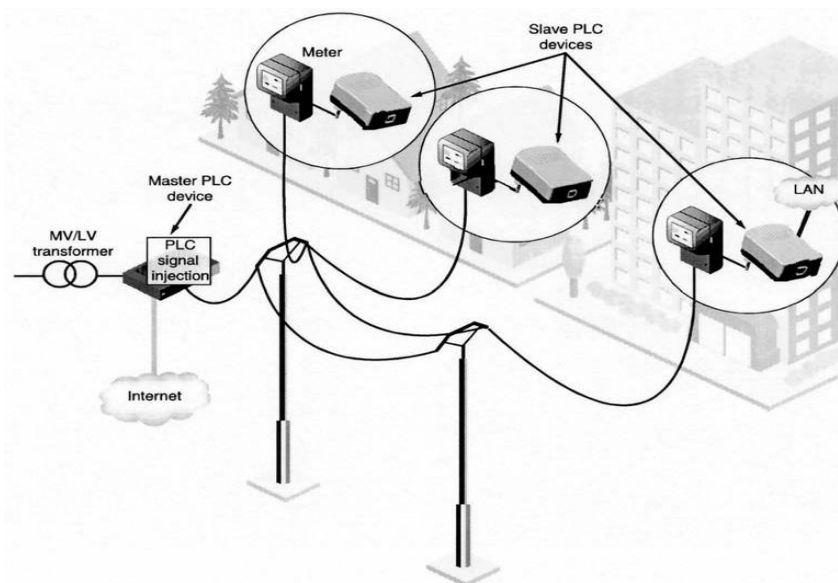

Fig. 9.1a: Simplified architecture of the master-slave mode

Some PLC devices are used for remote telephone interfaces over the PLC network. Some companies for example, develop devices with RJ-11 interfaces to carry voice analog communications over the electrical network. In the master –slave mode, a master device is at a high hierarchical level (it manages and controls the network), and the slave devices are at a lower hierarchical level (their function is limited to communications with the master device). In peer-to-peer mode, all the devices have the same hierarchical level and exchange data with all the other PLC devices of the network. Therefore, the network consists of N to N links. As illustrated in figure (9.1b), the peer-to-peer mode is ideal for local area networks since the LAN architecture must enable any terminal (typically PC) to exchange data with any other LAN terminal.Homeplug1.0 and Turbo use this mode.
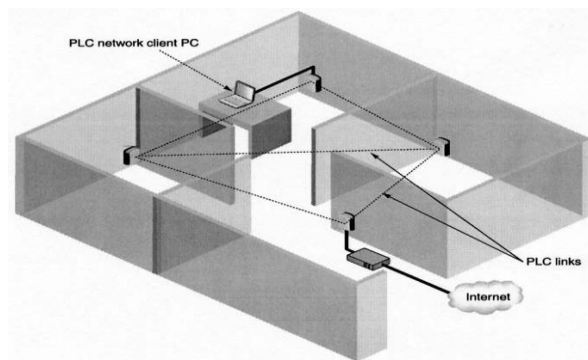

Fig. 9.1b: Architecture of a PLC network in peer-to-peer mode

PLC Modems

As PLC technology intrinsically uses the electrical network, the PLC devices, irrespective of their nature, connect to the outlets or directly inject the signal into the electrical wirings. This allows a PLC device to connect directly to the electrical wirings. Although the PLC technology does not use the modulation-demodulation process implemented in the modems, we talk about a PLC modem to designate the device to which the terminals that want to take part in the PLC network are connected.The PLC modem, which is the most widespread device in the PLC networks, is also the easiest to use, since it appears as a standard electrical appliance fitted with a male receptacle to be connected into an outlet and a USB or Ethernet interface to be connected to the terminal. When viewed from the outside, a PLC modem therefore has the two following interfaces:

- Male receptacle.
- RJ-45 Ethernet or USB network interface.

The modem generally has three indicators (LED) that indicate the presence of the 110 to 220V/50 to 60 Hz, PLC signal on the electrical interface and that of the Ethernet network on the RJ-45 interface to the user (see Figure (9.2a)).

Some devices have up to five indicator lights so that the user can check that the device is in good working order.

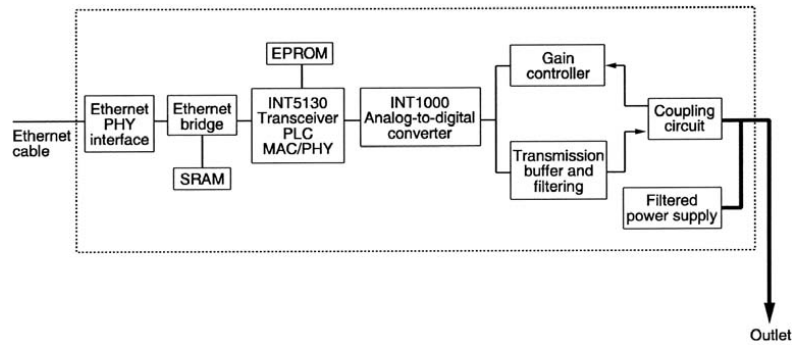**Fig. 9.2a: Outside of a HomePlug Power PLC modem**

Fig. 9.2b: Hardware architecture of a PLC modem

The manufacturers have developed two types of PLC modems: "desktop" modems, which appear as packages to be placed on a table or on a pedestal, with a cord to connect to outlets; and "wallmount" modems, which appear as integrated packages directly connected into outlets. Most PLC modems are wallmount modems since they are easy to use. Figure (9.2c) illustrates examples of wallmount (left) and desktop (right) modem
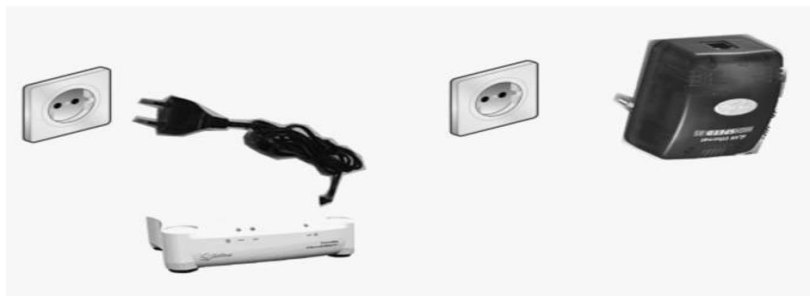

Fig. 9.2c: Wallmount and desktop PLC modems

PLC Ethernet Modems

The generalization of network interface cards in computers, network terminals, and electronic devices, even in household appliances, simplifies the building of networks by using the Ethernet board's RJ-45 connectors. This type of modem has become the most widely used PLC device. As well as being simple to use and configure, its price continues to fall. Figure (9.2.1) illustrates an Ethernet PLC modem of the companies Ethernet High Speed 85 type. The Ethernet network interface card of PLC modems was the first of the 10 baseT type (10 Mbit/s) for HomePlug 1.0 modems providing a maximum useful throughput at the MAC layer level of 8.2 Mbit/s, then of the 100baseT type (100 Mbit/s) for HomePlug Turbo and AV modems.

Fig: 9.2.1 Ethernet PLC modem

The increased performance of HomePlug PLC devices will probably lead the manufacturers to use 1,000baseT (1,000 Mbit/s) boards so that the throughput is not limited over the Ethernet interface. It would not be surprising to come across optical fiber PLC devices.

Practical Implantation

Figure (9.3) gives the block diagram of PLC system which we design on our project.
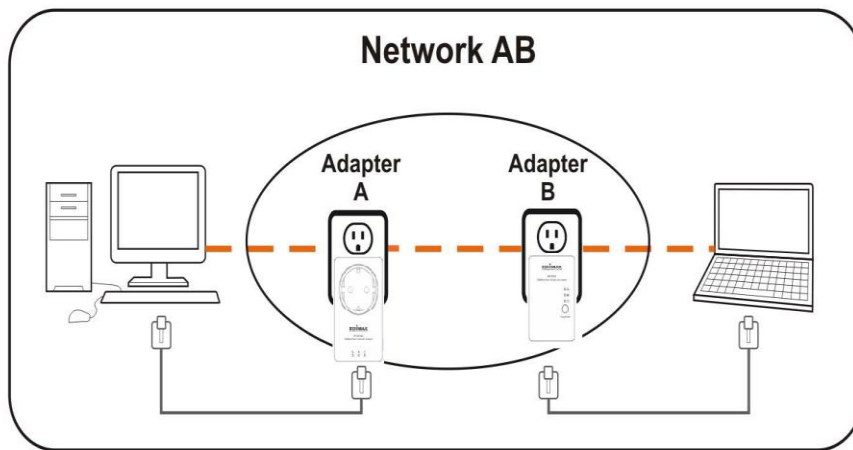

Fig. 9.3: Schematic diagram of PLC system

This design included the two computers connected in peer-to-peer mode, two power line adapters with Ethernet cables, and Transmission range up to 300 meters. The design requirement, computer with Ethernet port, running Windows XP/vista/7, Linux, MAC OSX and any other operating system. Any connected devices must feature a network port, and utility software supports windows XP/vista/7.

Connection set up : Connect a power line adapter to your computer 'A" (router) via Ethernet cable, and then plug it into a power socket.
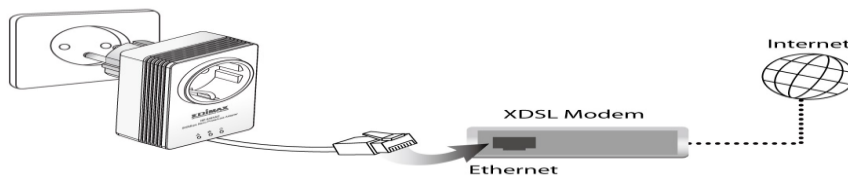

Fig. 9.3.1a: Illustrated the connection for computer "A" (Router)

▪ Connect another power line adapter to your computer, and then plug it into a power socket.
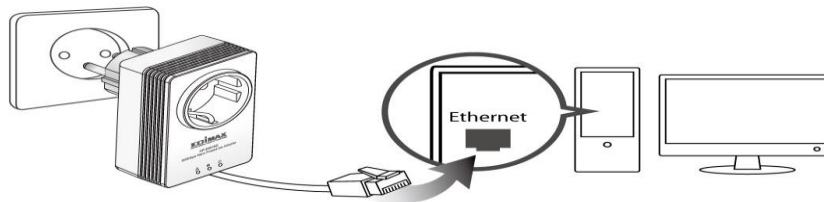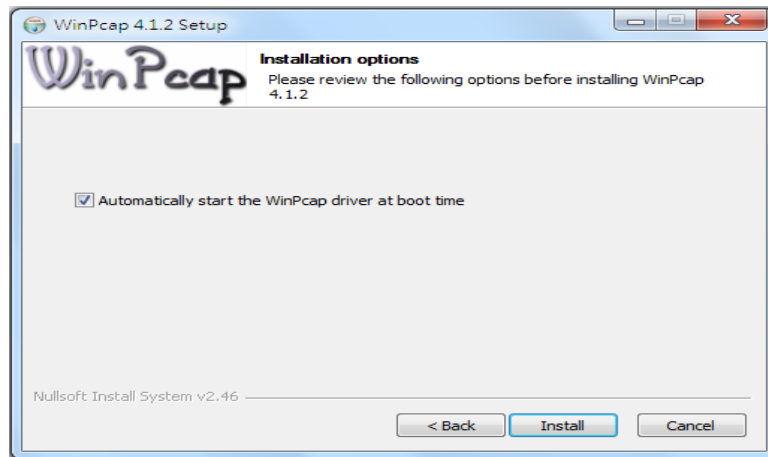

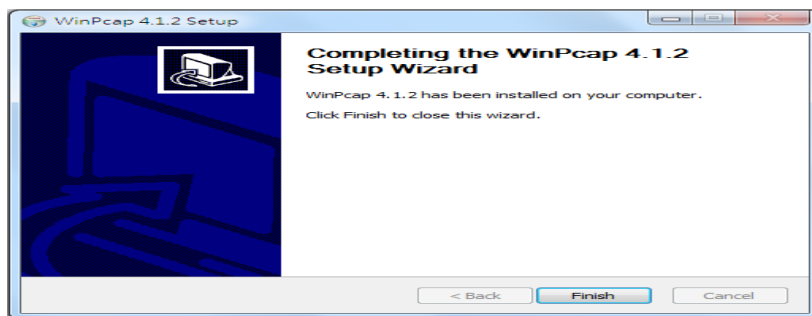**Fig. 9.3.1b: Illustrate the connection to the other computer**

We can also connect the adapter to a printer, set top box, gaming console, TV or other device with a network port, to add the device into the power line network.
▪ We monitor that on PLC and LAN LEDs light up on both PLC adapters.
▪ The computer "B" and the router (Computer "A") will be connected to the power line network automatically.
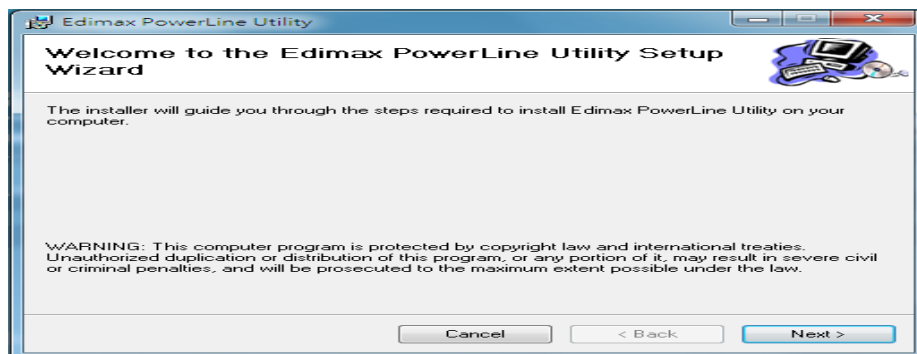▪ Then click "Setup Utility".

The wizard will guide you through the entire win Pcap installation.

- Then click install.

- Winpcap 4.1.2 has been installed on your computer. Click finish to close the wizard.

- After click finish the above dialog will appears .We go through this procedure until we reached the end of installation.
  After the installation finished connect the computer "A" with Internet after reply from the other computer. Proxing the Internet on the computer "B".

Testing Operation of the PLC Network

Once the various PLC devices of the network are configured, it is recommended that you check the good operation of the domestic installation network links by performing a test with the PLC configuration tool. To test the good operation of the PLC network, it can also be useful to run

"Ping" commands from the PC connected to the PLC network at adapter (A), to the LAB Top computer connected to that network at adapter (B),
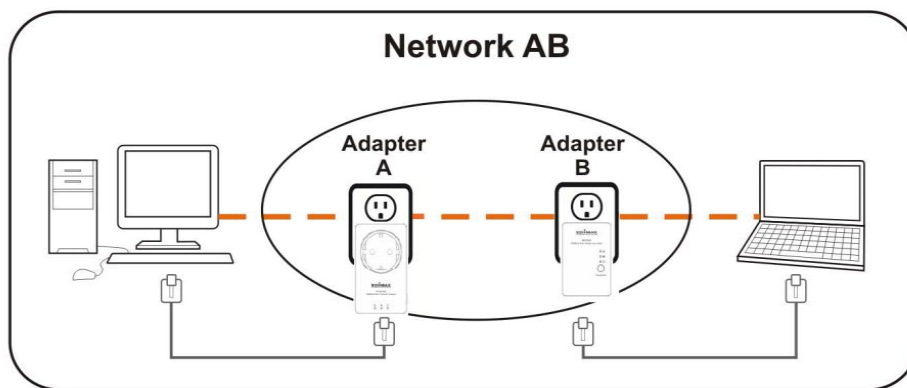
As illustrated in Figure bellow.

Fig. 9.4: Schematic diagram of PLC system

For this purpose, all the PCs or terminals must be in the same addressing plane (for example, for an IP network of the 192.168.10.1 for computer @ adapter A and the other devices in IP =192.168.10.100, 101,102 and so forth). @ Adapter B or others.

To start the "Ping" command, just proceed as follows:

- Click on "Start" then on "Execute."
- Enter cmd. A DOS window opens.
- Enter the following command:
  C:\>ping 192.168.10.1
  Pinging 192.168.10.1 with 32 bytes of data:
  Reply of 192.168.10.1: bytes=32 time=3 ms TTL=64
  Reply of 192.168.10.1: bytes=32 time=2 ms TTL=64
  Reply of 192.168.10.1: bytes=32 time=2 ms TTL=64
  Reply of 192.168.10.1: bytes=32 time=2 ms TTL=64
  If replies are sent back with this command, this means that the network links are configured and ready to be used by this application.

VII. CONCLUSION

This project has been a successful one with all project aims and goals are met. Addressing the individual project goals, a number of conclusions can be made. After detailed studies, we have gained an in-depth knowledge of the issues faced with power line carrier communications with three phases.

So, today's point of view the first challenge is to reduce the cost. So, in future we definitely proved that power line communication is the most efficient, powerful & cheapest media of communication.

- We have addressed possible methods to overcome these issues, mainly noise and attenuation caused in the power line.
- We introduced the possible uses of PLC techniques.
- The PLC system we designed is a primary stage of a home networking system in which we tried to send a data from one computer to another which is installed in the same building.
- A successful power line carrier communication link could be created by the addition of frequency hopping, variable gain stage and error correction techniques.

REFERENCES

[1]   Xavier Carcelle.- Power Line Communications in Practice
[2]   Klaus Dostert. Prentice Hall. 2001. Powerline Communications"
[3]   Hrasnica, Haidine, and Lehnert. Wiley. 2004, "Broadband Powerline Communications Network Design."
[4]   Gotz, Rapp, and Dosert, University of Karlsruhe. IEEE Communications Magazine. April 2004. Power
[5]   Line Channel Characteristics and Their Effect on Communication System Design."
[6]   Jerry Ramie. Conformity. October 2005. Review of FCC Report & Order 04-245 on Broadband Over   Power Lines (BPL)."
[7]   www.powerlineworld.com